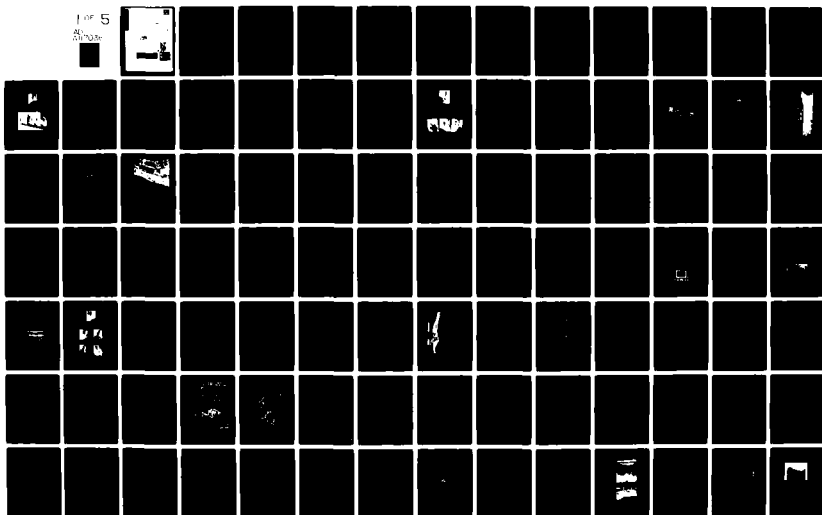


ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS F/G 8/5  
U.S. ARMY CORPS OF ENGINEERS SURVEYING REQUIREMENTS MEETING, 2---ETC(U)  
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U. S. Army Corps of Engineers

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## SURVEYING REQUIREMENTS MEETING

2-5 February 1982



April 1982

U. S. Army Engineer Waterways Experiment Station

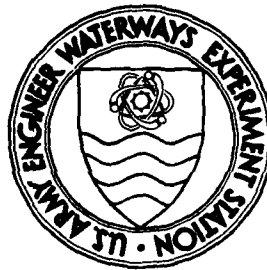
CORPS OF ENGINEERS

Vicksburg, Mississippi

U. S. Army Corps of Engineers

## **SURVEYING REQUIREMENTS MEETING**

2-5 February 1982



April 1982

U. S. Army Engineer Waterways Experiment Station  
CORPS OF ENGINEERS  
Vicksburg, Mississippi

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# FOREWORD

This publication summarizes the proceedings of the Corps Surveying Requirements Meeting held at the Sheraton Hotel, Jacksonville, Florida, on 2-5 February 1982. The meeting which combined land and hydrographic surveying was held to encourage a continuing exchange of ideas, methods, and experiences of District surveying personnel. The experience and knowledge thus gained will be beneficial to the Corps surveying improvement objectives.

The meeting was sponsored by the Office, Chief of Engineers, under the Surveying and Mapping Program of the Surveying and Satellite Applications Research Area. The objective of the research program is to ensure effective and efficient surveying systems and methods for Corps use.

These proceedings were compiled by Mr. E. D. Hart of the Hydraulics Laboratory (HL), and Mr. G. C. Downing of the Instrumentation Services Division (ISD) under the general supervision of Mr. M. B. Boyd, Chief, Hydraulic Analysis Division, HL, Mr. H. B. Simmons, Chief, HL, and Mr. F. P. Hanes, Chief, ISD, U. S. Army Engineer Waterways Experiment Station (WES).

Colonel Tilford C. Creel, CE, was Commander and Director of WES during the period of the meeting and preparation of the proceedings. Mr. F. R. Brown was Technical Director.

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U.S. Army Corps of Engineers  
Surveying Requirements Meeting

TECHNICAL SESSIONS  
ITEMIZED AGENDA

2-5 FEBRUARY 1982

TUESDAY - 2 FEBRUARY

8:00am - 9:30am

OFFICIAL CONFERENCE OPENING

Administrative Remarks - Ed East, Conference Chairman  
Welcoming - LTC Raymond F. Vachon, Deputy District  
Engineer, Jacksonville District  
- Mr. Ivan Clare, Admin. Assistant to the  
Mayor, City of Jacksonville  
Key Note Address - COL William T. Stockhausen,  
Director, Defense Mapping School

9:30am - 10:00am

BREAK

10:00am - 11:30am

TECHNICAL SESSION 1

(Hydrographic Equipment Developments)

1. Session Overview-  
Chairman: Dale Hart, WES
2. Waterways Experiment Station Activities Overview-  
Dale Hart, WES
3. Hydrography Equipment Development and Test in NOAA-  
David Enabit, NOAA
4. New Developments in Hydrographic Surveying-  
Colin G. Weeks, Wimpol Inc.
5. A New Generation Portable Echo Sounder -  
B.L. Keen, ODOM Offshore Surveys, Inc.
6. General Discussions - Chairman and Panel Members

11:30am - 1:30pm

LUNCH

1:30pm - 3:00pm

TECHNICAL SESSION 2

(Hydrographic Sweep Systems)

1. Session Overview-  
Chairman: George Downing, WES
2. Missouri River 16 Transducer Channel Sweeping Sounding  
System- William Allcock, Kansas City District
3. Performance Characteristics of the Bathymetric Swath  
Survey System and the Hippy Ship Motion Sensor-  
Don Pryor, NOAA
4. Total Bottom Mapping Survey Sweep System -  
H.F. Wentzell, Krupp International Inc.
5. General Discussions - Chairman and Panel Members

3:00pm - 3:30pm

BREAK

3:30pm - 5:00pm

TECHNICAL SESSION 3

(Dredging Surveys)

1. Session Overview -  
Chairmen: Bill Murden, WRSC and Roger Pruhs,  
Norfolk District

2. Management and Monitoring of Dredge Material Disposal Sites through Precision Bathymetric Survey Techniques - Robert Morton, Science Applications, Inc.
3. Improvements to Hydrographic Survey Systems for Dredging Surveys - Steve DeLoach, Norfolk District.
4. Modified Sub-bottom Profiler to Identify and Measure Dredge and Borrow Material - Ron Penton, Ocean Research Equipment, Inc.
5. General Discussions - Chairman and Panel Members

**WEDNESDAY - 3 FEBRUARY**

8:00am - 9:30am

**TECHNICAL SESSION 4**

(Tides)

1. Session Overview-  
Chairman: M. K. Miles, OCE
2. National Tidal Datum Convention of 1980 -  
A. Nicholas Bodnar, Lt. Cdm., NOAA, NOS
3. Implimentation of a New Concept in Offshore Tide Gaging- Eugene Batty, Norfolk District
4. A Portable Tidal Data Telemetry System for Hydrograhic Surveys- Bob Spies, Philadelphia District
5. Tidal Datums for Mean High Water Line Location-  
Paul O'Hargan, Craven Thompson
6. General Disscussions - Chairman and Panel Members

9:30am - 10:00am

**BREAK**

10:00am - 11:30am

**TECHNICAL SESSION 5**

(Hydrographic Surveying - Miscellaneous Topics)

1. Session Overview-  
Chairman: Glenn Boone, Wilmington District
2. A Microprocessor Based Survey Tracking and Control System for Small Sound Boats-  
David Pearson, Science Applications, Inc.
3. Performance Evaluation of Surveyboat RODOLF-  
Dave Sims, Portland District
4. A Simplified Procedure for Field Calibration of Electronic Line-of-Sight Positioning Systems-  
Glenn Boone, Wilington District
5. Surf-zone and Nearshore Surveying with the CRAB and a Total Station- Bill Birkemeier, CERC
6. General Discussions - Chairman and Panel Members

11:30am - 1:30pm

**LUNCH**

1:30pm - 3:00pm

**TECHNICAL SESSION 6**

(Hydrographic Data Processing)

1. Session Overview-  
Chairman: Bill Bergen, Jacksonville District
2. Automated Hydrographic Data Processing in the Jacksonville District-James Sheriff, Jacksonville District

3. Surveying and Processing Hydrographic and Topographic Data on the Coosa River- Jimmy Reaves, Mobile District
4. Corps of Engineers Digital Data for National Ocean Survey Nautical Charts- Dale Ross, Lt.(jg), NOAA, NOS
5. General Discussions - Chairman and Panel Members

3:00pm - 3:30pm

3:30pm - 5:00pm

BREAK

#### ACSM ACTIVITIES

1. Introduction to the South Atlantic States Unit and the Committee on Marine Surveying and Mapping- Bob Masterson, Unit Chairman
2. National/International Overview of Professional Relationships - Walt Robillard, ACSM President Elect.
3. Hydrographer Certification Program- James Collins, GPH Consultants
4. Corps of Engineers Surveying and Mapping Activities - M. K. Miles, OCE
5. What the ACSM and the 1982 Convention Will Do for You- Ed Brownell, ACSM Past President
6. Summary of ACSM's Government Affairs Committee Activities- Bill Wallace, Committee Chairman

THURSDAY - 4 FEBRUARY

8:00am - 9:30am

#### TECHNICAL SESSION 7

(Topographic Equipment Development)

1. Session Overview- Chairman: Ed Roof, ETL
2. A North-Seeking Gyro Attachment for Theodolites- Lloyd Penland, Wild (No Paper)
3. A Pulsed Gas Laser Distance Meter- Marshall Brown, K&E
4. Inertial Surveying- Ed Roof, ETL (No Paper)
5. Inertial Surveying- John Wickham, World Survey Inc.
6. Global Positioning System (GPS) Geodetic Receivers- Walt Senus, DMA (No paper)
7. General Discussions - Chairman and Panel Members

BREAK

9:30am - 10:00am

10:00am - 11:30am

#### TECHNICAL SESSION 8

(Airborne Lasers)

1. Session Overview- Chairman: Ed Link, WES
2. The Hydrographic Airborne Laser Sounder (HALS) - Walt Senus, DMA
3. Aerial Profiling of Terrain System - Bill Chapman, USGS, NMD
4. Preliminary Results of Shoreline Mapping Investigations Conducted at Wrightsville Beach, N.C.- Bill Krabill, NASA, Wallops
5. Airborne Lasers for Elevation Mapping - Philip Bailey, WES (No Paper)
6. General Discussion - Chairman and Panel Members

11:30am - 1:30pm  
1:30pm - 3:00pm

LUNCH

TECHNICAL SESSION 9

(Control)

1. Session Overview-  
Chairman : M. K. Miles, OCE
2. The Importance of Control Verification In Obtaining  
"True Positions"-  
Trevor Parish, Murphy/Parish/Kilgore
3. North American Datum (NAD) of 1983 and National  
Geodetic Vertical Datum (NGVD) of 1987 - Jim Stem,  
NGS
4. Geodetic Control Surveys, State of Michigan, 1981-  
Thomas F. Conlon, Jr., SPAN International, Inc
5. General Discussions - Chairman and Panel Members

3:00pm - 3:30pm  
3:30pm - 5:00pm

BREAK

TECHNICAL SESSION 10

(Photogrammetry)

1. Session Overview-  
Chairman: Jack Erlandson, Seattle District
2. Surveying and Mapping Applications of the APPS - IV  
Plotter - Jonathan Howland, Autometric  
Incorporated
3. Photogrammetry in Boundary Surveying -  
Jack Erlandson, Seattle District
4. Photogrammetric Beach Mapping and Monitoring Using  
Interactive Graphics for Plotting Cross Sections  
and Volume Computations- David Nale, Aerial Data  
Reductions Associates, Inc.
5. General Discussions - Chairman and Panel Members

FRIDAY - 5 FEBRUARY  
8:00am - 9:30am

TECHNICAL SESSION 11

(Monitoring Structures)

1. Session Overview-  
Chairman: Ken Robertson, ETL
2. Precise Deformation Surveys of Earth Dams  
Using Trilateration and Triangulation Techniques-  
Steve Johnson, VPI & SU
3. Measuring Tilt with an Automatic Level-  
Ken Robertson, ETL
4. Precise Deformation Surveys of the Dworshak Dam  
Using ETL's Trilateration Techniques-  
Darrel Martin, Walla Walla District (No Paper)
5. General Discussions - Chairman and Panel Members

9:30am - 10:00am  
10:00am - 11:30am

BREAK

TECHNICAL SESSION 12

(Topographic Surveying-Miscellaneous Topics)

1. Session Overview-  
Chairman: Jimmy Reaves, Mobile District
2. Towards An Integrated Field Data Collection Method -  
Harry Coupland, Marshall/Macklin/Managhan
3. Encroachment Surveys for Lands on the Intracoastal  
Waterways - Cleveland Powell, Jacksonville District
4. Modernization of Public Land Survey System-  
Doug Wilcox, Bureau of Land Management



11:30am - 12:00N

5. General Discussions - Chairman and Panel Members  
TECHNICAL WRAP-UP SESSION  
(Hydrographic and Topographic Sessions)

1. Session Overview-

Chairman: Ed East, OCE

2. Hydrographic Technical Sessions Summaries-

Each Session Chairman, No. 1 thru 6

3. Topographic Technical Sessions Summaries-

Each Session Chairman, No. 7 thru 12

4. Closing Remarks

12:00N

TECHNICAL SESSIONS ADJOURN

OFFICIAL CONFERENCE OPENING



Ed East  
OCE  
Conference  
Chairman



M. K. Miles, OCE, Conference Coordinator; Ed East, OCE, Conference  
Chairman, LTC Raymond F. Vachon, Deputy District Engineer, Jackson-  
ville District, Welcoming Address; COL William T. Stockhausen,  
Director, Defense Mapping School, Keynote Speaker

U. S. ARMY CORPS OF ENGINEERS  
SURVEYING REQUIREMENTS MEETING

1-5 February 1982

INTRODUCTION

The U. S. Army Corps of Engineers conducted the Surveying Requirements Meeting on 1-5 February 1982. The Jacksonville District acted as host to the meeting which was held in the Jacksonville Sheraton at St. John's Hotel.

Corps attendees included representatives of 7 Divisions, 35 Districts, U. S. Army Engineer Topographic Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), and the Office, Chief of Engineers (OCE).

Other U. S. agencies represented were the National Oceanographic and Atmospheric Administration, National Aeronautics and Space Administration, National Geodetic Survey, U. S. Naval Oceanographic Office, U. S. Department of Justice, U. S. Defense Mapping Agency, U. S. Bureau of Land Management, U. S. Geological Survey, Florida Department of Natural Resources, The State of Florida, and the Commonwealth of Massachusetts. Representatives were also present from the cities of Clearwater and Jacksonville, Florida, the American Congress of Surveying and Mapping, the Virginia Polytechnic Institute, and the University of Florida.

The 5-day meeting included Corps-only management sessions all day on Monday, 1 February, the evenings of Wednesday and Thursday, and Friday afternoon. The results of these sessions are covered in a separate document.

The open conference consisted of the presentation of 49 technical papers by government and private individuals. Surveying equipment was displayed and demonstrated by private vendors at 50 exhibit booths and aboard 8 survey boats.

Mr. E. J. East, representative of OCE, acted as Meeting Chairman. He was assisted by Mr. M. K. Miles, also of OCE. Mr. Bill Bergen and other employees of the Jacksonville District acted as coordinators and hosts. Messers. G. C. Downing and E. D. Hart of WES acted as coordinators of the exhibits and demonstrations.

## WELCOMING REMARKS

by

LTC Raymond Vachon  
Deputy District Engineer  
Jacksonville District

Good Morning! Welcome to the Jacksonville District. As Deputy District Engineer, and on behalf of the District Engineer, COL Devereaux, the Jacksonville District is extremely happy to have this opportunity to host the first Corps of Engineers Surveying Requirements Meeting.

I am pleased to note that this is the first Corps-wide conference designed to encompass the full spectrum of surveying, mapping, hydrographic, geodetic, and photogrammetric activities of both the Civil Works and Military Construction Programs. These technical disciplines are an important part of the overall mission of the Corps of Engineers to maintain the maximum readiness and effectiveness of the U. S. Army--on the battlefield, in garrison, during mobilization, and in special tasks involving the development and management of the nation's water and related land resources. I am confident that this expanded conference will enhance the Corps' mission as an integral part of the combined arms team.

The Jacksonville District is heavily involved in Civil Works construction, operations, and maintenance programs throughout Florida, Puerto Rico, and the U. S. Virgin Islands. I am sure you are all well aware that the design, construction, and maintenance of all Corps Civil Works and Military Programs depend heavily upon the surveying and mapping activities which will be addressed this week. The survey equipment, procedures, and instrumentation displayed and discussed during this conference will enhance the efficiency and effectiveness of our overall mission.

I am particularly impressed with the varied scope of the topics to be covered during the technical sessions. The diverse subjects include airborne laser terrain modeling systems, subsurface profiling systems, and structural deformation monitoring systems, to name just a few. I, therefore, encourage everyone to take full advantage of these sessions. Mr. Ed East and Mr. M. K. Miles from the Civil Works Directorate, Office, Chief of Engineers, are to be commended for organizing this varied technical program.

The exhibits on display, both those here in the hotel ballroom area and those aboard the survey vessels berthed alongside the hotel, are quite extensive and comprehensive. They represent a significant effort and expense on the part of the private manufacturing and architectural-engineering firms. This support to the Corps conference is sincerely appreciated, and I suggest that all those in attendance make a concerted effort to visit these exhibits during the coming week. The Waterways Experiment Station in Vicksburg, Mississippi, and Jacksonville District's Engineering and Construction-Operations Divisions have also gone to considerable effort to set up and support these exhibits.

I have noted from the registration roster that a large number of people are here from the private sector. We also have many individuals from foreign countries. I would like to officially welcome them on behalf of the Corps of Engineers.

I am sure that all of you will be busy with the work at hand for the remainder of the week. I am extending the full cooperation and support of the Jacksonville District personnel who stand ready to assist you in making your visit a pleasant and rewarding one.

# WELCOMING REMARKS

by

Mr. Ivan Clare  
Administrative Assistant to the Mayor  
Jacksonville, Florida

Welcome! I would like to briefly discuss some of the Corps of Engineers Projects in the Jacksonville area.

1. Harbor Deeping and Channel Maintenance--Port traffic exceeded 16 million tons in 1980, and the Port of Jacksonville showed a 22% increase in revenues for the first quarter of 1981-82. Jacksonville Shipyards continue to grow in customers, thanks to the work of the Corps in maintaining the channel downstream. The Tovex Corps study is nearly completed, recommending a deepening to 44 feet, but federal funding is a question mark. It would accommodate coal, phosphate, and petroleum ships.
2. Beaches Renourishment Project--This is much more than an environmental improvement for Jacksonville. \$10 million was well-spent to encourage tourism development here. 250 wholesale tour brokers from 28 countries were here for Florida Huddle and many commented on the beauty of our beaches, calling them superior to any in South Florida. This could be a tourism boon for us when they put together their 1983 packages. More than \$200 million was spent in Florida last year just from the Florida Huddle contracts.
3. Water Resource Needs Study--Completed in 1980.
4. Mill Cove Study--Dredging plan approved, but no funding available.

## KEYNOTE ADDRESS

by

William T. Stockhausen  
Director, Defense Mapping School  
Ft. Belvoir, Virginia

Good morning ladies and gentlemen. On behalf of MG Richard Wells, Director of Defense Mapping School (DMA), I'd like to express DMA's appreciation at being invited to participate in your 1st triannual survey requirements meeting. DMA is a joint service agency whose mission is to provide the mapping, charting, and geodesy support required by the Department of Defense, including the military services, the Unified and Specified Commands and other Department of Defense (DoD) agencies. Also by statute, DMA is responsible for providing nautical charts and marine navigation data for all vessels of the United States and of navigators in general. I'm sure some of you are not aware, but there is a long and deep tie between DMA and the Corps. In fact, most of the Army assets that became part of DMA when it was formed in 1972 came out of the military side of the Corps. The old Army Map Service, which later became the production element of the U. S. Army Topographic Command, is now one of DMA's major production centers, the Hydro/Topo Center, still located in Brookmount, Maryland, just west of Washington, D. C., where it has been for over 40 years. The Defense Mapping School originally was the Department of Topography of the Engineer School, Ft. Belvoir, Virginia, and the (Inter-American Geodetic Survey (IAGS) was a Corps agency. DMA's other major production element, the Aerospace Center (AC) located in St. Louis, Missouri, came over from the Air Force and the Office of Distribution Services (ODS) was organized in 1978 to consolidate map and chart distribution previously handled by HTC and AC. Many of our long-time civilian employees started with the Corps and over 90% of our Army officers are engineers. Additionally, one of the three flag officers within DMA is always an Army general, and traditionally has always been an engineer officer. In fact, our current director, MG Wells, came directly to DMA last summer from serving as the North Pacific Division engineer. But, the ties between our two agencies are not just historical or people-related: they are mission-related as well. Topographic and hydrographic surveying are integral functions of DMA in carrying out our worldwide mission of providing mapping, charting and geodetic support to DoD and the military services, as they are for the Corps in carrying out your overall construction and regulatory missions. For example, DMA, as is the Corps, will be deeply involved in the MX Missile Deployment Program regardless of the option finally selected. Highly accurate gravity data as well as positioning data are critical to improved missile accuracy. Surveyors from DMA's Geodetic Survey Squadron (GSS) also provide instrumentation support for missile firings at Vandenberg AFB, white sands missile range, The Eastern Space and Missile Center at Cape Kennedy, and on Kwajalein Atoll in the South Pacific, as well as support such specialized facilities as the Central Interior Guidance Test Facility and The High Speed Sled Test Track. GSS also provides precise position of B-52 parking points so that aircrews can align, calibrate, and initiate their navigation systems. GSS has even been involved in support of NASA's Space Shuttle by providing precise runway alignments on the dry lake bed at Edwards AFB where the shuttles return from space.

Another area of similarity involves training. The Corps has an extensive training program for your civilian surveyor force. I in turn, as Director of DMS, am responsible for training all of the Army's military construction surveyors as well as providing formal geodetic survey training for Army, Air Force, Navy, and Marine Corps personnel. Our basic construction survey course lasts 15 weeks, the basic geodetic course 14 weeks, an intermediate geodetic course 12 weeks, an advanced geodetic course about 14 weeks, and a new hydrographic surveying course being developed for the Marine Corps, roughly 5-7 weeks. In addition, we provide a 3-1/2-week block of geodetic surveying as part of our all service MC&G officers' course.

Last but not least, we conduct a resident training course on operation of the Analytical Photogrammetric Positioning System (APPS) plus provide mobile training team support to deployed Army, Navy, Air Force, and Marine Corps units.

Now let's look for a few moments at some of the dynamic changes in equipment and techniques that have occurred in our business during the past 20 years. The transit and steel tape have been superseded by infrared devices and lasers. Programmable calculators and minicomputer systems have virtually eliminated tedious and time-consuming computations. Inertial positioning systems mounted in commercial vehicles and helicopters have been developed, tested, and proven both accurate and reliable for geodetic control densification on numerous projects all over the globe. In fact, the Army is about to field a militarized version known as PADS "The Position and Azimuth Determining System" which not only is GI-proof but will revolutionize field artillery fire control by providing a common grid system linking firing battery centers, target acquisition sites, and observation posts at essentially the rate of movement of the tactical forces. Although designed as a fifth-order (1:1000) system, test results substantiate the conclusion that PADS will meet fourth-order (1:10,000) requirements as well as determine azimuths well within the 1-mil accuracy constraints. In addition, Corps artillery as well as the supporting engineer topographic units are equipped with the APPS, plus DMA-produced Point-Position Data Bases (PPDB) for rapid expedient target location as well as friendly survey control. With the fielding of doppler equipment as part of the Army's new Topographic Support System (TSS), the survey capabilities of the Engr-Topo units will be further enhanced. However, the real advances are still to come with the fielding of the NAVSTAR Global Positioning System (GPS), the details of which you will be hearing later in the week. Suffice it to say, GPS is a DOD Satellite program developed primarily for defense navigation but with tremendous potential for conducting geodetic surveying as well. The implications for the military are mind-boggling. For the first time continuous, real-time navigation of ships, planes, tanks, self-propelled artillery, and individual small units will be a possibility. Fire on the move by individual artillery pieces will at last be a reality. As for surveying, DMA is currently developing a GPS-Compatible Geodetic Receiver to deliver high-quality survey control in a matter of a few hours observation by a one- or two-person team. Without a doubt, the marrying of GPS with the inertial systems will have a dramatic impact on the way geodetic and cadastral control will be installed in the future.

Also charging on to the battlefield are a myriad of intelligence, target acquisition, weapons and command and control systems to provide our forces an edge in fighting outnumbered and sometimes outgunned as well. These systems will provide us the ability to locate the enemy, discriminate as to his composition, prioritize his importance as a target, relay

the information to a firing unit, and insure first round hits all in a real or near real time sense. At the heart of such systems is a marrying of microprocessing and remote sensing technology interacting with a digital terrain data base. No longer is the mapping and survey function in a supporting role; it is an integral part of the system and as essential for success as the gunpowder or rocket motor.

The Cruise Missile System, for example, will use a guidance and control technique known as TERCOM. DMA-produced digital data tailored along preplanned flight lines will be stored on board the missile in the form of elevation reference scenes. The missile will sense terrain scenes enroute and provide an error signal to update the inertial navigation system. The Army's Pershing II Missile employs a technique of radar reference scene correlation during its final stages of flight to "Home-In" on its target. DMA-generated digital data will be used to create radar reference scenes which will be stored in digital form on board the missile. As the missile approaches the target area, it will sense a series of radar scenes which will be correlated with the predicted scenes and appropriate course adjustment signals sent to the missile's guidance system. The Army's Firefinder, Mortar-Artillery Locating Radar System also uses digital elevation data to backtrack the flight of enemy rounds, while still in the air, to their points of origin. This permits us to handle multiple rounds from multiple launchers simultaneously and return accurate counter-battery fire in a matter of seconds, thereby catching the enemy firers before they have had time to displace.

Clearly, these few examples are only the "tip-of-the-iceberg" of future requirements for digital data. DMA's dilemma is not how to acquire the data, but how to avoid being buried under the avalanche of satellite and inertially derived geodetic control and a flood of multisensor, multi-spectral high altitude imagery which will be available. Ours is clearly a problem of management rather than of technology, and we are wrestling with that bear today trying to decide on data base formats and architecture not only to optimize our own storage, retrieval, and update capabilities, but the formats and structure for fieldable terrain data bases to provide the services for their respective uses.

Now let's focus for a few minutes on the purpose of this meeting. It's called a survey requirements meeting, but what we really will be talking about for the next 4 days is technology transfer. In simplest terms, your requirement, as is DMA's, is to do an effective job, on schedule, with minimum resource expenditure. Developing technology and techniques plus improved management will be presented as possible ways to meet that requirement. Your dilemma is one of decision--standing pat on your current method of survey operations or sorting through the myriad of developing technologies and choosing the ones that are right, given your particular set of circumstances. What is right for DMA is not necessarily right for you. What is right in Omaha is not always applicable in Jacksonville. A high-risk venture at best, but certainly one with high payoff potential as a reward for a correct decision. Good luck with those decisions.

Now, let's hear what the experts have to tell us.

Thank you.



SESSION I: HYDROGRAPHIC EQUIPMENT DEVELOPMENTS



Dale Hart  
WES  
Chairman  
(also Speaker)

*Speakers*



David Enabitt  
NOAA



Colin Weeks,  
Wimpol, Inc.



Brad Keen  
Odom Offshore Surveys,  
Inc.

## SESSION I

### HYDROGRAPHIC EQUIPMENT DEVELOPMENTS

#### Summary

The Waterways Experiment Station (WES) has completed equipment developments which include a small boat data logger, stream velocity meter, and a depth scanning system. Currently, a heave correction system is being developed. This work is being coordinated with National Oceanographic and Atmospheric Administration (NOAA) and private firms. The NOAA is working on a number of developments including airborne laser hydrography and the Swath Survey System. Test results are presented of the Datawell heave, roll, and pitch measuring equipment and two positioning systems: Raydist DRS and Argo DM-54.

From the private sector (Wimpol, Inc., and Odom Offshore Surveys, Inc.), a number of units of surveying equipment applicable to Corps needs were discussed. These included:

- a. Automated hydrographic data collection and processing system.
- b. Swath survey system.
- c. Telemetry unit.
- d. Digital echo sounder.

## WATERWAYS EXPERIMENT STATION ACTIVITIES OVERVIEW

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### BIOGRAPHICAL SKETCH

Mr. Hart is a civil engineering graduate receiving his BS from New Mexico State and MS from Colorado State. He worked in the Little Rock District as a civil engineer in Project Planning. Since 1966 he has been employed at the Waterways Experiment Station serving as a supervisory research hydraulic engineer in the Prototype Evaluation Branch. Duties include supervising hydraulic field measurements at Corps structures and coordinating the Corps' Hydrographic Surveying Systems R&D program.

### ABSTRACT

A group was established within the U. S. Army Corps of Engineers to coordinate with the Corps Districts in the procurement and development of modern, efficient hydrographic surveying systems. Objectives and accomplishments of the group to date are discussed.

### INTRODUCTION

The Congress of the United States requires the Corps of Engineers to continually survey Federal waterways within the boundaries of the 38 Engineer Districts. The surveys are made for the purposes of determining channel depths for navigation, measurement of areas subject to scour or silting, determination of quantities of streambed excavation, and location of submerged objects.

The surveyor is concerned primarily with the configuration of the bed of the waterway and its accuracy is dependent upon his ability to determine the horizontal position of the recorded depths within acceptable limits. The efficiency of such surveys is dependent on the time and cost involved in achieving such accuracy. Therefore, the objective of the Corps of Engineers is to provide the given accuracy in the required time at the least cost to the government.

The Waterways Experiment Station (WES) located at Vicksburg, Mississippi, is the research arm of the Corps. The Office, Chief of Engineers, Washington, D. C., assigned the Hydraulics Laboratory of WES the responsibility of coordinating with the Districts in the development and procurement of modern, efficient hydrographic surveying systems. A coordinating group consisting of the author and an electronic engineer from the WES Instrumentation Services Division was established.

Coordination of the development program has consisted basically of the following steps.

- a. Search available literature to determine the state of the art.
- b. Canvas manufacturers to locate new or improved equipment and determine development activities in progress.

- c. Survey District offices to obtain specific information on requirements, current practices, suggested improvements, and future needs.
- d. Survey other organizations engaged in hydrographic surveying.
- e. Witness and evaluate integrated systems in actual survey conditions.
- f. Advise Districts of findings and make recommendations where desired.

At the end of the first year all of the above objectives had been achieved or were in progress. As a conclusion to the first year of study, and a springboard into the next, a Corps of Engineers Hydrographic Survey Conference was conducted at WES in May of 1972. The conference will be discussed subsequently.

#### CONSIDERATIONS OF AUTOMATION

Surveying and dredging operations of the Corps of Engineers are faced with a universal situation, getting more done with less personnel. Fortunately, technological improvements make it possible to do this. By automating surveying and dredging operations dramatic improvements in production have been achieved.

Automated operations require large capital expenditures, retraining of employees, and, in general, a new way of doing things. However, these initial liabilities are more than compensated for by the long-range benefits of an automated system. In survey work automation can effect savings by reducing preparation, data collection, and processing times and necessary field personnel. Generally, inclement weather is a less significant factor to be considered in survey scheduling. These facets of the total effort emphasize that the usefulness of automatic equipment must be judged on the basis of the savings to the overall operation and not on survey savings alone.

The investment in equipment (boats, electronic gear, ADP equipment, etc.) is a major consideration and carries a price tag which makes its cost simple enough to determine. The expenses of designing and programming an automated system are less obvious but just as real. They also represent a sizeable percentage of the total system cost. Training costs are another intangible which must receive a generous allocation of funding. The automation cost can be unbearably high if the purchaser demands excessive functions, accuracy, and redundancy. The purchaser must make a careful, unbiased review of what is actually required.

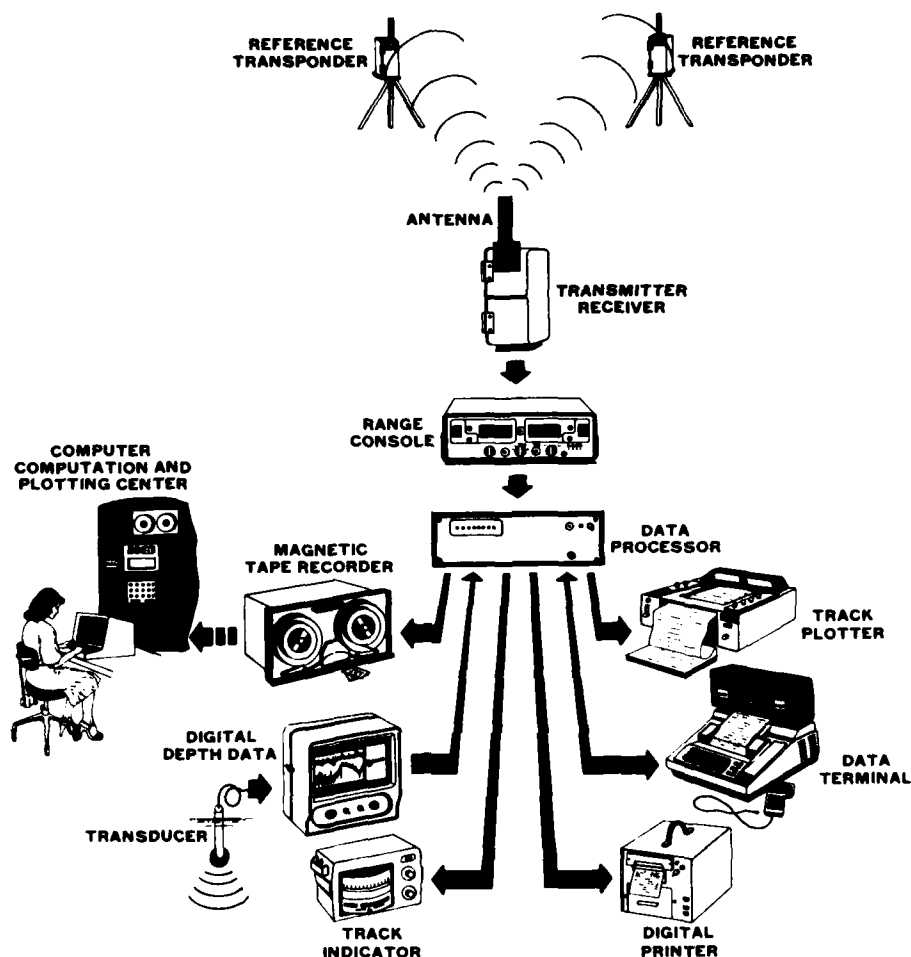
#### EQUIPMENT FUNCTIONS

The automated equipment of current usage is expected to perform four basic functions for the hydrographic surveyor. These functions are:

- a. Measure needed information and present in machine readable form (i.e., electrical signals).
- b. Process the measured information as needed to interface with associated equipment.
- c. Record information in machine readable form (i.e., magnetic or paper tape).

d. Display information to the pilot for course guidance.

A schematic of an automated hydrographic surveying system is presented in figure 1.



*Courtesy Motorola, Inc.*

FIGURE 1. Hydrographic Survey System

The size and arrangement of the survey boat will influence the choice of an automated system. The amount of data processing considered necessary aboard the boat will also have an important bearing on equipment selection. If the survey boat equipment is kept to a minimum the major data processing burden can be placed on the District Automatic Data Processing Center. This approach favors the use of several smaller survey boats with data recording equipment only, as compared to one large boat which both collects and processes the data. Figure 2 illustrates a typical boat equipped for data collection only.

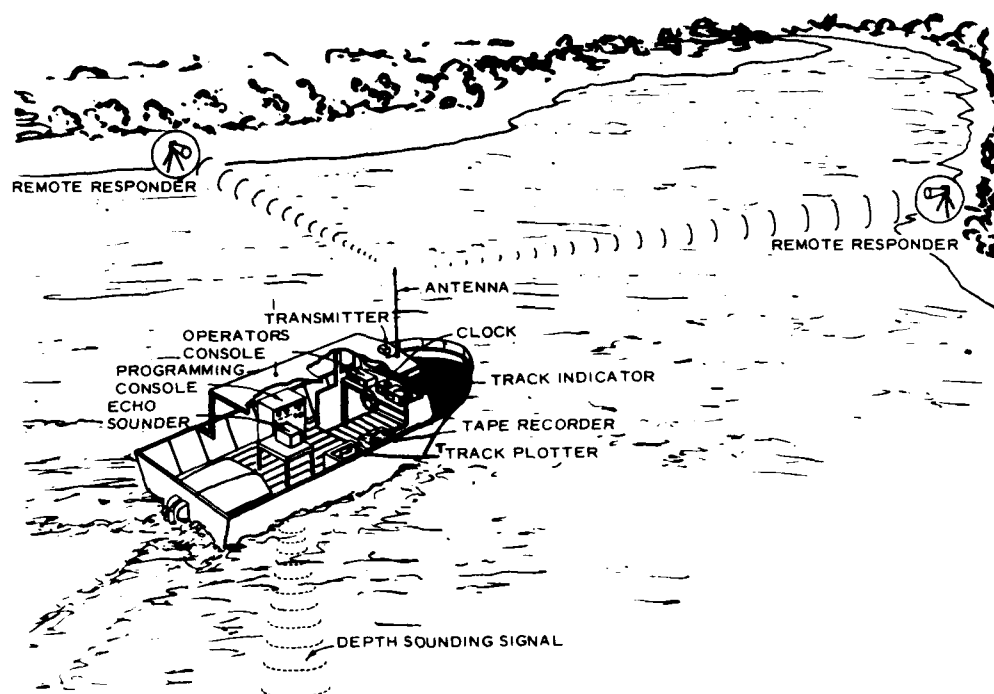


FIGURE 2. Data Collecting Hydrographic Survey Boat

#### HYDROGRAPHIC SURVEY CONFERENCE

To insure that personnel of the District offices were aware of existing electronic equipment a Corps of Engineers Hydrographic Survey Conference was conducted at the WES on 9-11 May 1972. The conference was attended by representatives of 36 Districts. Also, employees of five other U. S. Government agencies as well as Canadian and Australian representatives were present. A total of 103 Government personnel attended.

The first two mornings of the conference were devoted to formal presentations of experiences with hydrographic surveying equipment by speakers from District offices. The afternoons and all of the third day consisted of discussions and demonstrations of equipment by 14 private firms. Field demonstrations were made aboard Corps survey boats, one (used in a later conference) is shown in figure 3. A total of seven (including this one) Corps conferences have now been held.

#### TRAINING

As the Corps acquired electronic components and systems the need for specially trained personnel became obvious. A Hydrographic Surveying Technicians Training Course was initiated in 1974 at the WES. Courses have been held every year since. The 1982 course will be held at WES on 1-5 March.

The course is divided into four sections; Hydrography, Radio Aids, ADP,



FIGURE 3. Corps Survey Boat

and Field Training. Two fully equipped survey boats are provided for the field training. A typical agenda is presented below.

1982 Hydrographic Survey Course  
Tentative Schedule

<u>Monday</u>	<u>Thursday</u>
0800 - Welcome	0930 - Hydr Soundings Lab
0830 - ADP - Minicomputer Intro	1000 - Break
0930 - Break	1030 - Hydr - Soundings Application
1000 - Hydrography - Control	1115 - Suspended Sediment and Soft Bottoms
1100 - Radio Aids (RA) - Intro	1215 - Lunch
1200 - Lunch	1330 - Hydr - Digital Depth Meas
1300 - ADP Peripheral Devices	1430 - Break
1400 - Private Firm Demo	1500 - ADP Large Computers
1500 - RA - Electromagnetic Waves	1600 - Hydr - Water Level Meas
1630 - Hydr - Soundings	1700 - Adjourn
1700 - Adjourn	1830 - Private Firm Demo
<u>Tuesday</u>	<u>Friday</u>
0800 - RA - Wave Propagation	0800 - RA - Calib & Accuracy - Low Freq
0900 - Hydr - Sounding Equipment	0900 - RA - Calib & Accuracy - High Freq
1000 - Break	1000 - Break
1030 - ADP - Number Systems	1030 - Field Operations - Low Freq
1130 - Hydr - Sounding Equipment	1130 - Field Operations - High Freq
1215 - Lunch	1230 - Lunch
1315 - Boats: Group I - "Arc" Group II - "PELICAN"	1330 - TBA
1700 - Adjourn	1430 - Test
<u>Wednesday</u>	1515 - Break
0830 - Boats: Group I - "PELICAN" Group II - "ARC"	1545 - Review
1200 - Lunch	1600 - Adjourn
1315 - ADP Signal Types	
1415 - Private Firm Demo	
1500 - Break	
1530 - Tour ADP Sites	
1700 - Adjourn	



#### DEVELOPMENTS

Coordination has been carried out with the districts and private industry in the development of surveying equipment for Corps use. Equipment developed include a channel sweep system, small boat data logger, and stream velocity meter.

Development of a heave correction system is now under way. Both doppler and inertial concepts are being studied. This effort is being closely coordinated with private industry and other Government agencies to prevent duplication of effort. Figure 4 depicts depth measuring problems created by uncorrected heave.

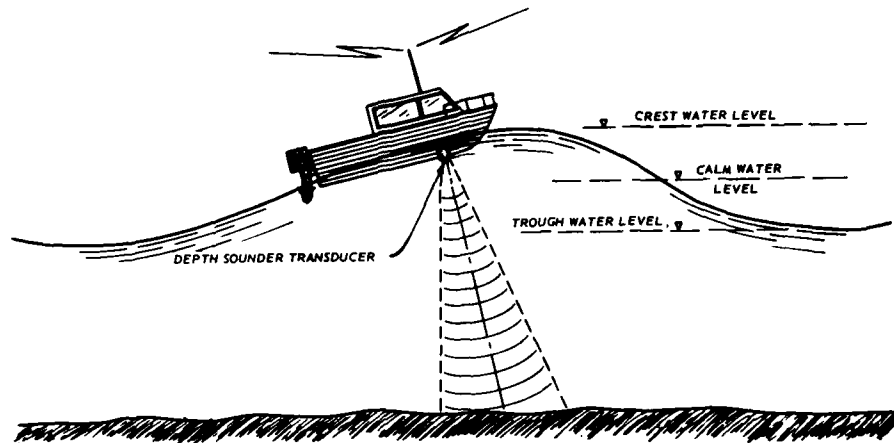


FIGURE 4. Depth Measuring Problems Created by Heave

#### SUMMARY

As stated previously the ultimate objective of hydrographic surveying is to provide an accurate plot of the channel depth. Such a plot is shown in figure 5, the end product of the survey.

A large portion of the funds allocated to the Corps of Engineers is expended for annual hydrographic surveying and dredging. Approximately 20,000 miles of navigation channel and 1,000 harbor projects must be maintained. The Corps is dedicated to continuous updating of hydrographic surveying methods, components, and systems of components to meet this assignment.

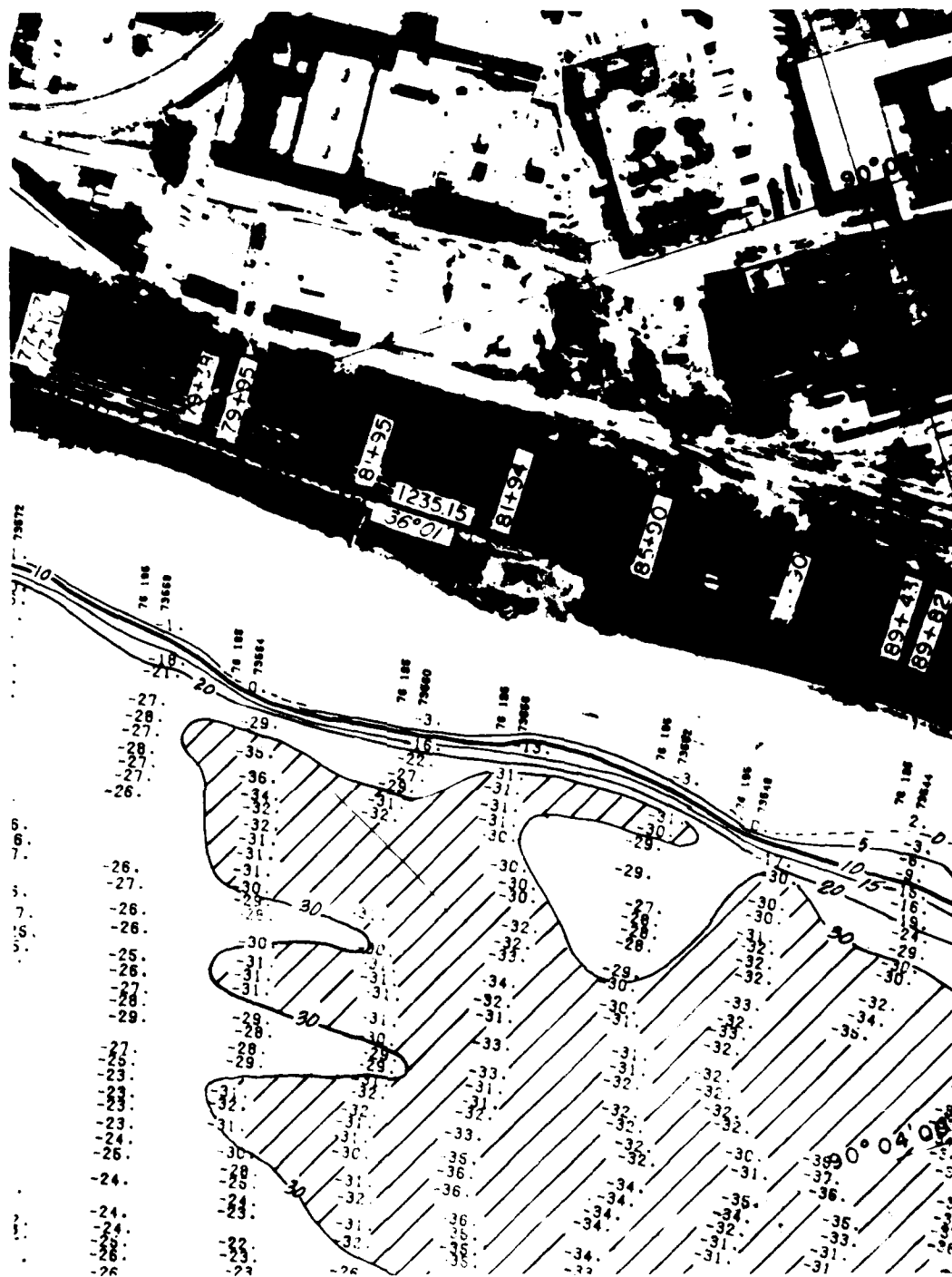


FIGURE 5. Map of Hydrographic Survey

## HYDROGRAPHY EQUIPMENT DEVELOPMENT AND TEST IN NOAA

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### BIOGRAPHICAL SKETCH

David B. Enabnit received a B.S. and M.S. in Physics from the Ohio State University. He is presently a physicist with the Office of Ocean Technology and Engineering Services (OTES) of NOAA. Most recently he was project manager of the NOAA Airborne Laser Hydrography Development Project. He is now the deputy manager of the Hydrography Systems Development Project for OTES.

### ABSTRACT

The status of several hydrographic equipment developments being done by and for NOAA are discussed. The developments discussed are: airborne laser hydrography, the Bathymetric Swath Survey System, the Fleet ADP system replacement, and the depth sounder replacement. Test results are also presented on three pieces of equipment used for hydrographic surveying. Those pieces of equipment are the Datawell HIPPY 120C heave, roll, and pitch measuring instrument the Raydist DRS positioning system, and the Argo DM-54 positioning system.

### INTRODUCTION

Hydrographic surveying equipment development for NOAA is performed on contract, by the Office of Ocean Technology and Engineering Services (OTES/NOAA), and by the National Ocean Survey (NOS/NOAA). In addition, regular testing is performed on new equipment to establish its suitability for NOAA. This paper will present information on several ongoing component and system developments applicable to hydrography. It will also discuss some of the hydrography related component and system testing being performed. Finally, generalizations will be made concerning problems that these new technologies are causing.

### AIRBORNE LASER HYDROGRAPHY DEVELOPMENT

NOAA has been developing airborne laser hydrography for several years. The technique uses an aircraft mounted, scanning beam, pulsed laser system to gather a swath of discrete soundings. It measures water depth using the same principle as sonar, but with light instead of sound.

The focus of the NOAA effort has been on performing a comprehensive evaluation of the technique and on performing research into the propagation of laser sounding pulses in

water in order to determine depth measuring accuracy and penetration capability. The evaluation portion of the work established several major facts:

1. The technique was able to measure water depths to within the 0.3 meter RMS accuracy standard over the set of conditions experienced. This was established by using an experimental NASA system to gather 1.5 million laser depth soundings in the Chesapeake Bay over a six month period.
2. A quantitative analysis showed that airborne laser hydrography could be performed for one-sixth the cost of conventional sonar surveys. This would save \$29 million over the 8-year system lifetime.
3. Another quantitative analysis showed that airborne laser hydrography required only one-fifth the manpower of conventional sonar surveys. This would save 196 staff years over the system lifetime.
4. The technique offered the added potential benefits of a 100-fold increase in the number of soundings per unit area and a 75 percent increase in the amount of shallow water surveyed annually.
5. 82,000 km<sup>2</sup> was estimated to be surveyable at 10 U.S. sites where sufficient water clarity data existed to make such an estimate. 82,000 km<sup>2</sup> equals 1.5 times the system lifetime capability.

The research portion of the airborne laser hydrography project involved a sophisticated computer simulation of the laser pulse propagation in water. This original research showed that the pulses would be severely distorted as a function of water optical properties, depth, the entry angle of the pulse, and system parameters. Depth measurement biases as great as one meter could result. Errors were found to be sufficiently dependent on environmental, system, and operating parameters that a one-time-only bias correction would be inadequate. Bias correction procedures were developed to allow laser measured depths to be corrected in post flight processing using the conditions that existed at the time of the sounding. The error producing effect of optical "layering" in the water was also simulated. It was concluded that less than 0.1 meter of error would result from ignoring the layered condition and assuming optical homogeneity.

NOAA is now awaiting funds with which to develop an operational airborne laser hydrography system. The results of the research and evaluation phase have been provided to the Naval Ocean Research and Development Activity where an operational system is being developed for Navy use.

#### BATHYMETRIC SWATH SURVEY SYSTEM (BS<sup>3</sup>) DEVELOPMENT

The BS<sup>3</sup> is a multibeam sonar system designed to gather hydrographic data in water depths from 25 to 2,000 feet.

The multibeam concept makes it possible to survey swaths of width equal to 2.5 times the depth. The basic components of the BS<sup>3</sup> were designed by General Instruments Corp. and delivered to NOAA in 1977. Software development and system tests were conducted from 1977 to 1979. Deficiency corrections and system modifications were made during 1980. In April, 1981, a series of tests were conducted to characterize the system.

The objective of the April BS<sup>3</sup> characterization tests were to determine the accuracy and reconnaissance capability of the system. Accuracy was measured by compiling statistics from successive BS<sup>3</sup> passes over an area and then comparing the results to international accuracy standards. Four such tests were completed in the Puget Sound, Washington, area. Ground truth was provided from a pressure sensor in one area and conventional depth sounders served as a basis for comparison in the other areas.

The BS<sup>3</sup> was found to meet international accuracy standards but with some limitations. The entire swath of 22 beams produced data within the required accuracy bounds in shallow water (90 feet) over a hard bottom. In similar water depths over a soft bottom, none of the beams in the swath were sufficiently accurate. In deep water (2200 feet) the central 14 beams were acceptably accurate but the outer four beams on each side were not. Data from the central beams were also acceptably accurate over a steeply sloped area. Data from the entire swath in this steeply sloping area might actually be within the accuracy bounds but the rugged bathymetry introduced variability which could not be separated from system variability. The variability of data from the center beams of the BS<sup>3</sup> was nearly as small as that from the conventional sounders in all tests except over the soft bottom. In order to achieve the accuracies described it was necessary to cull the soundings on the basis of the amplitude of the return. These tests showed that low amplitude returns and "second bottom reflections" should be rejected in order to achieve suitable accuracy.

The reconnaissance capability of the BS<sup>3</sup> was determined in a variety of ways. In one test it was found that in 90 feet of water a two foot triplane was too small to be detected in the real-time contour plots displayed for the hydrographer (at least against the background of soundings from a soft bottom). Examination of the post-processed data showed that the target had actually been detected on 47 percent of the runs over it. In another test the wreckage of a tanker in 270 feet of water, covering approximately 100 feet square and rising about 48 feet above the bottom was clearly detectable both in real-time and in the recorded data.

The ability of the BS<sup>3</sup> to detect natural features such as shoals and pinnacles was also tested. Three features with least depths of 180, 220, and 300 feet in general depths of 350 feet were surveyed. The output from these surveys were examined by two hydrographers.

Both hydrographers interpreted the system's real-time outputs in the same way. They were able to extract least depths and locations of features that were consistent with the sounding plot from the conventional depth sounders. They were able to distinguish between features that were insignificant (rising less than ten percent above the general bottom) and those that required further development.

In summary, these tests have shown that the BS<sup>3</sup> can be used for hydrographic operations so long as the area does not have a soft bottom and so long as the data from the outer four beams on both sides are not used. The effects on chart accuracy of algorithms which select among all BS<sup>3</sup> soundings for the minimum, significant subset have not yet been addressed. Intercomparison with the conventional sounder data using tools developed in this analysis can quickly indicate whether bottom conditions will seriously affect the data quality. The tests have also shown that the BS<sup>3</sup> has significant value as a reconnaissance and bathymetric tool. The test results provide a quantitative basis for developing strategies using the system to minimize time required in these operations.

It is planned that the BS<sup>3</sup> will be transferred from developmental to operational status within 12 months.

#### NOAA FLEET ADP SYSTEM REPLACEMENT

One of the most significant problems facing NOS/NOAA in the 1980's is the fact that the majority of the ADP systems used by or in support of NOAA Fleet activities are approaching the end of their useful life. Also, existing Fleet ADP systems are not capable of satisfying projected program requirements. To correct this deficiency, NOS/NOAA intends to acquire a new generation of ADP equipment to replace and upgrade the existing systems used throughout the NOAA Fleet, and at the Atlantic and Pacific Marine Centers.

Hydrographic surveying encompasses approximately 80 percent of the Fleet's computer system inventory and this will establish most of the replacement system's characteristics. The new Fleet ADP system is envisioned as two distinct subsystems: a Data Acquisition Subsystem (DAS) and a Data Processing Subsystem (DPS). The DAS will: acquire and record data from sensor subsystems, such as depth sounders, and from operator terminals; monitor data validity; provide steering guidance to the vessel operator; and generate survey track and sounding plots in near real-time. For planning purposes, the DAS is envisioned as including a processor, a date/time clock, a pen plotter, two cartridge tape drives, two floppy disk drives, one alphanumeric terminal, one serial printer, and interfaces to the sensors.

The DPS will: store project data; transfer digital data; select and process hydrography data; perform automated quality assurance functions; allow operator examination and editing of data; perform utility computations; allow digitizing of graphic and handwritten data; generate printed

data and text; and generate graphic data plots. For planning purposes, the DPS is envisioned as including: a processor, a pen plotter, two cartridge magnetic tapes drives, two reel-to-reel magnetic tape drives, three disk drives, one line printer/plotter, two alphanumeric CTR's, two serial printers, and three graphic CRT's, one of which should have a digitizing pad.

The Fleet ADP system replacement is seen as a system development effort in that existing state-of-the-art components (CPU's, cartridge tape drives, ...) will be integrated in a manner uniquely suited to NOAA needs. Software is expected to be developed by the government rather than on contract. The technical specifications for this new Fleet ADP system are written and are presently undergoing review and revision.

#### DEPTH SOUNDER REPLACEMENT

As with the Fleet computers, the present echo sounders used by NOS/NOAA for hydrography are approaching the end of their useful life. Reliability is problematic and maintenance requirements are increasing. Technical specifications have been written for a replacement depth sounder, a competitive procurement conducted, and an award made. The depth sounder selected is the Raytheon DSF 6000N, an evolutionary development of the Raytheon DSF 600. NOS/NOAA plans to buy 24 of these depth sounders at \$12K each.

The DSF 6000N is a dual frequency echo sounder capable of simultaneous operation on both frequencies. The 100 KHz, high frequency beam is 7.5 degrees wide at the -6 dB point and transmits a circular pattern. One KW of peak power will be transmitted. The design operational depth range is from 1 meter to 400-500 meters. The high frequency beam is intended to define the location of the bottom and will be presented on the analog depth display with only one level of gray. The 24 KHz, low frequency beam is 26 degrees wide fore and aft and 47 degrees wide athwartship at the -6 dB point, thus transmitting a rectangular pattern. Two KW of peak power will be transmitted. The design operating depth range is from 2.5 meters to 400-600 meters. The low frequency beam is intended to determine the character of the bottom. Return signals from the 24 KHz beam will be presented on the analog depth display with eight levels of gray.

For both high and low frequency beams, the digital recorded data will have a depth resolution of 0.1 meter. The accuracy will be  $\pm 0.01$  percent of depth due to clock errors. The sounding rates are: five per second in 0-75 meter depths, two per second in 75-200 meter depths, one per second in 200-400 meter depths, and 0.5 per second in 400-800 meter depths. The DSF 6000N depth sounder is microprocessor controlled and based on the Z1LOG Z80 microprocessor. The unit is expected to weight 20 kg, have a mean time between failure of 3061 hours and a mean time to repair of 0.35 hours. The first DSF 6000N is expected to be delivered to NOS/NOAA in May 1982. Acceptance tests will be

performed by both Raytheon and NOAA and the units will then be deployed.

#### VESSEL MOTION CORRECTION TESTS

Vessel motion is a significant depth measurement error source during hydrographic surveys. NOAA has been investigating means to remove heave, roll, and pitch induced depth errors with periods up to 60 seconds and to an accuracy of 0.3 feet of heave and  $0.003 \times \text{depth}$  for pointing errors. The pointing error translates to a pointing measurement of 0.3 degrees for vertical sounding beams and as little as 0.1 degrees for the off-vertical beams of the NOAA Bathymetric Swath Survey System.

The Datawell HIPPY 120C was recently tested by NOAA against these requirements. This instrument uses a long period pendulum as a vertical reference. The pendulum period of 120 seconds is achieved by suspending the pendulum in a fluid in which it is almost neutrally bouyant. The platform supports an accelerometer to provide heave data and a pair of crossed coils to measure pitch and roll. These coils sense magnetic fields generated at different frequencies by crossed coils on the instrument case.

Three types of tests were performed to characterize the HIPPY 120C: static and dynamic laboratory tests, tests with the instrument mounted in a van, and field tests. The static laboratory tests checked the zero offset of the roll and pitch outputs. They were found to be within the manufacturer's specification of 0.1 degree. Dynamic laboratory tests were performed to measure the frequency response of the instrument to dynamic heave, roll, and pitch. The experimentally observed frequency response of delayed heave was in agreement with the manufacturer's specifications. The peak output of roll and pitch were determined to be correct to within one or two percent up to the effective experimental limit of 0.125 KHz.

Van-mounted tests were performed to examine errors introduced by horizontal accelerations. These pendulum-disturbing accelerations are produced during ship maneuvers. Results of these tests were in qualitative agreement with a mathematical model of horizontal acceleration produced errors. Consequently, such errors are expected to be minor.

Field tests were performed with the HIPPY 120C mounted in a 55-foot vessel. These tests allowed observation of HIPPY performance over a flat sea bottom with moderately high waves (five feet). Deviations of HIPPY-corrected soundings from the expected, flat profile give an upper bound on HIPPY errors and uncorrected heave, roll, and pitch induced depth errors. Repeatability of depth profiles over preset courses were also used to help bound the errors. These field tests showed that the upper bound on the error in depth correction is on the order of 0.2 feet using delayed heave.



The conclusion of the Datawell HIPPY 120C characterization tests is that this instrument appears to have adequate accuracy for motion correction of hydrographic data for motions with periods as long as 30 seconds.

No further development or testing of vessel motion correction instrumentation is in progress. NOAA has no immediate plans for implementing such systems in the operational survey vessels.

#### POSITIONING SYSTEMS TESTS

NOAA has a continuing project of positioning system testing in order to define system accuracy and to establish operational limits on system use. In October, 1979, the latest version of the Raydist DRS system was tested. Stability tests were performed under static conditions to determine the long term (greater than eight hours) and the short term (less than one hour) variations in range data as contributors to system accuracy. The test range was a 225 kilometer stretch of the Atlantic Ocean between Oregon Inlet, N.C. and Assateague Island, Va. Short term stability was determined from 400 range data points taken at six second intervals over 40 minutes. Long term stability was measured over periods ranging from 8-12 hours to several days.

The effective daytime range of the Raydist DRS system as tested was determined to be in excess of 225 km. The daytime effective range determination from the test data is valid between 6:30 AM - 4:00 PM using the highest (21 knots) tracking rate. Lane jumps occurred in this mode at approximately 5 PM on two occasions. The lane losses were presumed to be caused by the onset of skywave interference from other sources as no significant variations in the shore station signal levels were noted during transitions in the lane count. In other operational areas when using the DRS system, the daytime operation hours may have to be adjusted to insure system operation free from interference effects. The expected daily long term stability between 6:30 AM - 4:00 PM using the maximum tracking rate was calculated to be 0.09 lanes or four meters. Use of the DRS system for hydrographic surveys on a daily basis requires a calibration point or position for comparison.

The effective night time range of the DRS system was determined to be less than 250 km with the antennas used in the tests. This conclusion is based on the inability of the DRS system to prevent lane jumps when using the slowest tracking rate (three knots) or the maximum filtering presently available in the system. Due to the continuous wave transmissions of the DRS system, all lane jump magnitudes recorded at the mobile station were one lane except on one occasion where a net loss of two lanes occurred within a very short time (80 min.).

The Raydist DRS system was very reliable during the entire testing period in that no equipment malfunctions occurred at either the shore or mobile station and no tuning adjustments were required at either site.

In January, 1980, stability tests were performed on the Cubic-Western Corporation's ARG0 DM-54 medium range positioning system. These static tests were designed to measure the effectiveness of a phase stabilization modification made by Cubic-Western as a result of the April 1979 tests conducted by NOAA. The test range and the measurement periods for short and long term stability determinations were the same as with the Raydist DRS system.

The use of phase stabilization resulted in a measurable improvement in the long term stability during daylight hours. The mean long term stability, measured over approximately ten hours, improved from 0.05 to 0.02 lanes when comparing the April, 1979, test data with the January, 1980, data at approximately equal ranges of 253 km and 224 km. The mean long term stability measured over five days improved from 0.2 to 0.12 lanes. Phase stabilization allowed the antenna impedance at the mobile and shore stations to vary over larger ranges without inducing sudden changes in the partial lane counts. The positioning net was able to operate with some detuning of the antennas, providing that the transmitted signal levels are above the threshold sensitivity level of the ARG0 receivers, and maintain nearly the same partial lane count in the range value as when the antennas are optimally tuned. The use of phase stabilization implies that the shore stations could be left unattended for longer periods of time, with some detuning of the antennas, and continue to transmit usable data to the mobile station.

There was basically no improvement in the effective night range. Lane losses and gains occurred during high interference levels using smoothing code 6 and higher. During adverse weather conditions, maximum editing and filtering had to be applied (smoothing code 9) to hold the lane count. However, there were test periods of a number of days where minimal filtering (smoothing code 2) could be applied on a 24 hour basis without lane jumps. An analysis of the data indicates that phase stabilization does not increase the effective range for a given transmitted power level and is not the contributing factor to the utilization of lower smoothing codes in holding the lane count readings at night. These factors are governed primarily by an increase in the transmitted power, achieved by using a larger antenna.

Recently, the Del Norte 520 DMU short range, microwave positioning system was tested. This unit is being considered as an upgrade of NOAA's existing Del Norte equipment. Test results of the 520 DMU have not yet been released.

The next section does not discuss the development or test of any specific hydrographic equipment. Rather, it deals with NOAA's ability to use existing and planned equipment.

## INTEGRATED LOGISTICS SUPPORT (ILS)

There is a concern within NOS/NOAA that the steady proliferation of sophisticated technology has brought with it an increased difficulty in providing logistic support for that sophisticated technology. The facts are that (a) logistical support crises do occur in NOS/NOAA, and (b) there are occasional equipment and system breakdowns which have had an adverse impact on operational performance. There is also evidence that we have to nurture new systems for an inordinately long time with excessive demands on both field operations and support personnel. Not only is there a penalty in the delay of operational effectiveness of these systems, but the heavy demands on both field operations and support personnel detract from established systems and operations. Resulting negative effects on data quality and data production are not known but intuitive feelings run high that they exist. This is certainly true of existing hydrographic equipment and as new, more sophisticated equipment is developed and deployed, will be of even greater concern.

Recognizing these facts, a study was performed to identify the causes, problems, and issues related to keeping NOS/NOAA data acquisition systems running efficiently and effectively. The study examined the ILS history of 18 existing and 2 developmental systems. The principal conclusions of that study were:

1. ILS practices in NOS/NOAA are inconsistent, unpredictable, and largely inadequate; emphasis on any one of the ILS principles varies from one equipment acquisition to the next; in any one acquisition process one or more principles are neglected.
2. Field Engineering Support groups compensate for deficiencies in ILS planning. It is suspected that this compensation is achieved at either or both (a) an excessive price for field support and (b) adverse impacts on data collection operations.
3. There is no formal overall NOS/NOAA policy that prescribes an orderly approach to the acquisition, deployment, and operational use of systems and equipment.
  - a. There is little evidence of program management control that correlates and integrates the various functions and activities related to the acquisition and operation of data acquisition systems in any given program.
  - b. There is no unit in NOS/NOAA dedicated to providing those engineering functions necessary to anticipate and solve technical problems that arise in:

1. new systems until they become operationally reliable and effective, and
2. existing systems that for a variety of reasons are not solvable by maintenance procedures.

Two principle recommendations of this study were that a systems acquisition policy, tailored for NOS/NOAA, be written and that an ILS policy and procedures be written stating the degree of consideration to be given to specific ILS issues during the acquisition of major and non-major systems. These recommendations were accepted and the appropriate policies and procedures are being written based on the Office of Management and Budget's A109 Circular, Department of Commerce's Administrative Order 208-3, and Department of Defense experience. It is expected that the implementation of the resulting policy will improve the ILS and field engineering support posture of NOS/NOAA.

#### CONCLUSIONS

The work just discussed summarizes most of the hydrographic equipment development and test being performed for NOAA. There are a couple recognizable trends in the new technologies which are expected to present problems. The first of those is the trend toward gathering more and more data. The BS<sup>3</sup> and laser hydrography systems gather large numbers of soundings per unit area. The replacement depth sounder takes two soundings at each location. Increasing amounts of supporting data are also going to be gathered such as heave, roll, and pitch correction data and signal strength measurements for quality control of positioning data. The added data presents two problems: data management and data quality control. Data management is the physical manipulation and storage of the information. Data quality control is the assurance that incorrect information is deleted and that in selecting a subset of the gathered data for charting purposes, the selected subset accurately reflects the bathymetry. Both data management and data quality control procedures are pushing NOAA towards higher levels of automation.

A second trend of new equipment is its increasing sophistication. Increased sophistication will accentuate the existing problems of maintenance, reliability, and keeping an adequate staff trained in the maintenance and operation of the equipment. A heavier reliance on automated systems with which one is one marginally familiar is a dangerous trend. For this reason, the management attention of NOS/NOAA to integrated logistics support is especially timely.

## NEW DEVELOPMENTS IN HYDROGRAPHIC SURVEY

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### BIOGRAPHICAL SKETCH

Colin G. Weeks specialized as a hydrographic surveyor in the Royal Navy in 1950 and spent 14 years in survey ships working in the North Sea, Far East and West Indies. Since coming to the U. S. in 1967 he has been Chief Surveyor of Decca Survey Systems Inc., President of The Hydrocarta Corporation, an independent consultant, and now Vice-President of Wimpol, Inc. He is a Fellow of the Royal Institution of Chartered Surveyors and a member of ACSM.

### ABSTRACT

The paper describes an automated hydrographic data collection and processing system, a swath survey system, and a system that can be used for the telemetry of field data and/or the remote control of field equipment.

### INTRODUCTION

Wimpol will be a new name to almost everyone here and I believe it would be helpful to introduce the company before discussing products. Wimpol Ltd. is a British company and is a relatively new name even in England since it was only formed about three years ago as a joint venture between Wimpey Laboratories and Polytechnic Marine - hence the name Wimpol. Polytechnic was strong in oil related surveys in the North Sea while the survey department of Wimpey Laboratories had been doing large scale hydrographic surveys for twenty years, primarily in support of Wimpey's activities in hydraulic modeling and port development, but they were also one of the two firms acceptable to the British Admiralty for carrying out hydrographic surveys under contract. Today however there is no connection with Polytechnic and the company is a wholly owned subsidiary of George Wimpey Ltd. - a fact of some importance in today's high technology world since George Wimpey is a major organization, with a worldwide group turnover in excess of two billion dollars and well able to provide the necessary financial backing.

Wimpol's work in the North Sea is primarily the provision of high accuracy positioning - typically  $\pm 5$  metres - 24 hours a day at a distance of 100-150 miles from the Scottish coast, using Syledis equipment permanently installed on the offshore platforms with the antennas at the tops of the derricks. We also offer Argo service chains and have had more than our share of the prestige jobs - the installation of some of those mammoth concrete platforms. In the Arabian Gulf we are a partner in what is probably the largest survey contract of the past few years; the Upper Zakum Field, in

which there are often 20 vessels being positioned simultaneously - survey vessels, pipeline barges, diver support vessels, etc. The pipeline right-of-ways are 15 metres wide, the positioning accuracy is being continuously checked, and payment stops if it is found to be worse than 2½ metres. That is absolute accuracy, not just repeatability, and again is achieved with Syledis.

Wimpol's U. S. subsidiary is in the process of being established in Houston as Wimpol Incorporated, with the main focus on oil related work in the Gulf of Mexico. However, systems that carry out pipeline surveys are equally suitable for hydrographic or dredging surveys; one of the purposes of our presence here is to tell you about some products and services that might be of interest and to explore the ways in which they might be used. We are a flexible company, ready to look at any reasonable business proposition, but with the Regulations as they are, it is unlikely that we shall be attempting to carry out survey work for the government ourselves.

#### A HYDROGRAPHIC SURVEY SYSTEM

So much for the company, now for the products - but I would stress that these are only the new developments; our existing range is covered on our stand in the Exhibition Hall. The first is an automated survey system, capable of producing complete hydrographic charts, drawing cross-sections and calculating dredge quantities. I do not want to say too much about the technical capabilities of the system, beyond the facts that it would have met the specifications of the Portland District for surveying at 20 knots in their hovercraft, the Roloff, and is a direct descendant of both the Hydrocarta system - used under contract to the St. Louis, Memphis and New Orleans Districts and operated by the U. S. Marine Corps and two Government Departments in Australia - and of the Hewlett-Packard based system used by the Pacific Division of the Corps of Engineers. It is based on the latest Hewlett-Packard desk top computers - either the 9826 or 9836 - and processes every depth measurement which the sounder takes, an imperative condition if depth selection is to be reliably accurate. The principal difference between this and the earlier systems is the ease with which the software may be modified by the user - for example, if the client is one of those Districts which have customarily printed out Northings before Eastings, and wants the computer to do the same, the program can be easily adapted to do so. This is a capability which is valuable to the surveyor, because every survey is different and these differences sometimes call for different computer programs.

A computer however is only a part of a survey system, albeit an important part, and it is of little use without a positioning system, a depth sounder, a depth digitizer, a printer, a recording device, and a plotter - and it is of even less use if these different components are not integrated with each other and with the software, to form a viable system. If Wimpol goes into this business, and whether we do or not will depend very much on the response we find during this meeting, it would be to lease entire systems containing all of the above items, the necessary interfaces, and the software. Assistance in installation would be available if required; training would be available on request. Thus an A/E firm with the local knowledge and experience could bid on major hydrographic contracts knowing that it would be fully supported - but knowing also that it would not be acquiring a financial millstone in the shape

of a major capital outlay on assets for which employment might not exist once that particular contract was complete.

### H<sub>3</sub>S - HYDROGRAPHIC SWATH SURVEY SYSTEM

As we all know, sounding lines have traditionally been run across the river, dodging between the barge trains as they go up and down. Our echo sounder tells us what is directly beneath the boat, but our sounding lines may be 200, 500 or 1,000 feet apart and of the depths between the lines we have no knowledge. For this reason, there has been increasing interest in 'swath' sounding, in which multiple transducers are arrayed perpendicular to the axis of the boat. The boat steams up and down channel, sounding a swath typically 100 feet wide, and by overlapping the swaths it is possible to obtain 100% sounding coverage. There are however practical problems with such systems in that the transducers are mounted on booms, attached to the ship, which can be deployed on either beam. If the booms are below water they must be of substantial construction and heavy hydraulically operated swivel fittings must be built into the vessel; if they are above water, the booms and rigging can be of lighter construction but it becomes dangerous if the vessel rolls enough to put the end of a boom in the water. With either type roll correction is essential since every degree of roll or list will cause an error of 10 inches at the end of a 50 foot boom, but in the past such correction has not normally been provided.

The other problem is in handling the immense amount of data collected. 21 transducers measuring 10 depths per second collect 756,000 depth measurements per hour, over 6 million per 8-hour day. To show each one in the conventional manner would require a piece of paper about 20 feet square. Each sounding must however be looked at or there is no point in doing the survey, so it can be seen that there is a data handling problem of no small magnitude - and if the system designer merely produces a reel of magnetic tape for someone else to process, in my opinion he is just passing the buck.

H<sub>3</sub>S - which stands for Hydrographic Swath Survey System - addresses both problems. The transducers are mounted on a 100 foot boom which floats independently of the ship on two catamarans 25 feet in from each end. The boom is towed ahead of the ship by two lines from the apex of an A-frame which projects over the bow of the vessel like a bowsprit. These lines run back to points on the boom above the catamarans and two further lines run from these same points back to each quarter of the vessel. The boom is thus decoupled from the rolling of the ship, yet is constrained to follow as the ship alters course or speed; the catamarans are free to rotate about a vertical axis so that they do not restrict manoeuvrability. The only modification required to the vessel is the provision of heel fittings for the A-frame and for the galleys that will normally be required to support it, so that the system can easily be transferred from ship to ship or into storage when not required. In offshore waters, of course, the boom is still subject to water motion; accelerometers at each end of the boom measure its movement and allow complete correction of the depths measured.

The other problem, presentation of the data, is met by use of a computer with a colour display. On a scale of about 1/4400, the 5 foot distance between the transducers is equivalent to the spacing

of the pixels - picture elements or spots of coloured light - on the display, and if each sounding is shown by a dot of light in its correct geographical position, with the colour determined by the depth, it can be seen that the depth contours will be self-evident. The surveyor can interpret them with a light pen to create a data file containing each contour, which may then be drawn on the plotter. The light pen can also be used to select soundings or to delimit areas within which quantities should be calculated.

Finally, it must be confessed that H<sub>3</sub>S is a paper tiger. It has not yet been built, nor will it be until a courageous customer places the first order. It is however well within the limits of current technology, and the risk, such as it is, is only one of delay in completion; not of failure to complete nor of cost overrun.

#### DATA TELEMETRY AND REMOTE CONTROL

The third product is not so much a product as the ability to design and engineer a product to meet a special application in the area of radio navigation or marine data collection. This is the task of Wimpol's System Engineering Department and is of course a very broad definition; I should like this morning to look at just one aspect and suggest some possible applications. This aspect is High Speed Data Communications, more commonly known as telemetry.

I would suggest that there is a greater need for telemetry today than there has ever been before. We need data over wider geographical areas, we need it more rapidly, but the staff to collect it is no longer available. On the other hand, having recognized the need for telemetry, one must also recognize that the great majority of such equipment is designed for an environment considerably more benign than that in which field equipment is normally required to operate.

On the Wimpol stand in the Exhibit Hall are two boxes which form a prototype Tributary Station which has been developed as part of an Area Navigation System for use around one of the North Sea oil fields. The concept is that the co-ordinates of every vessel in the vicinity will be telemetered to a Command Station, every few seconds, for display on a monitor which will also show - in different colours - the position of each platform, pipeline, restricted area, etc. Another system is in production for use in Norway to control remotely the operation of a permanent Argo navigation system.

It is not suggested that either of these applications will be appropriate for anyone here, but let me suggest some possibilities closer to home that might set you thinking:

- a set of water level and water flow meters connected by radio or telephone link to the District Office, so that decisions can be based on up to the minute data the next time that the Mississippi floods. Used in the reverse direction commands could be sent to open flood gates or sluice valves, without the necessity for human intervention on site.
- improving the accuracy of Loran-C by telemetering pattern shifts from a receiver on a fixed point close to the survey area, so that corrections can be applied automatically and continuously to a receiver on board.



- ensuring that dredge spoil is dumped in the designated spoil ground without the necessity for an inspector on board. This would require telemetry of position readings - and Loran-C would often be of adequate accuracy - together with the ship's draft, so that the period and position of dumping could be observed from the record in the shore office. One of the attractions of such a system is that the data is handled within black boxes to which the personnel on board do not have access - so it would be difficult to fudge.

The building blocks on which such systems are based offer the following features:

- absolute data integrity, through synchronous communications
- the ability to communicate in both directions between the Command Station and up to 256 Tributary Stations
- programmable intelligence in every station
- availability of multiple inputs and outputs at each Tributary Station, both analog and digital
- suitable for use with UHF, VHF and HF radio, the public telephone system, or a mixture of the two
- environmental housings designed for the locality in which they are to be used

If any of you have a telemetry application, Mr. Tony Hamblin, our Engineering Manager in the U. K., is here for the whole of this week, and I suggest that you contact either him or myself. Wimpol prides itself as being in the forefront of what is today a high technology industry - but we cannot help to solve problems unless the people in the field tell us what their problems are.

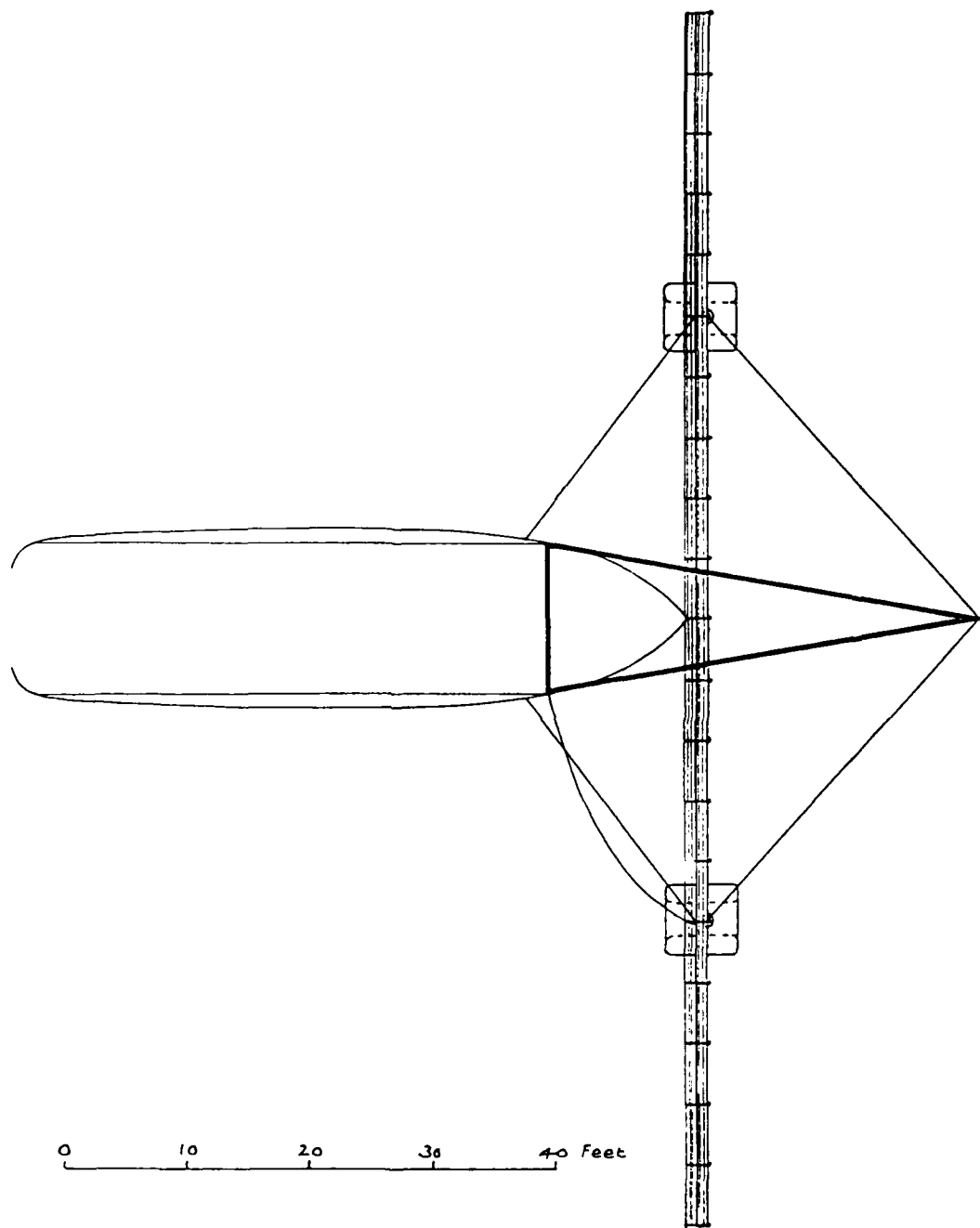


FIGURE 1

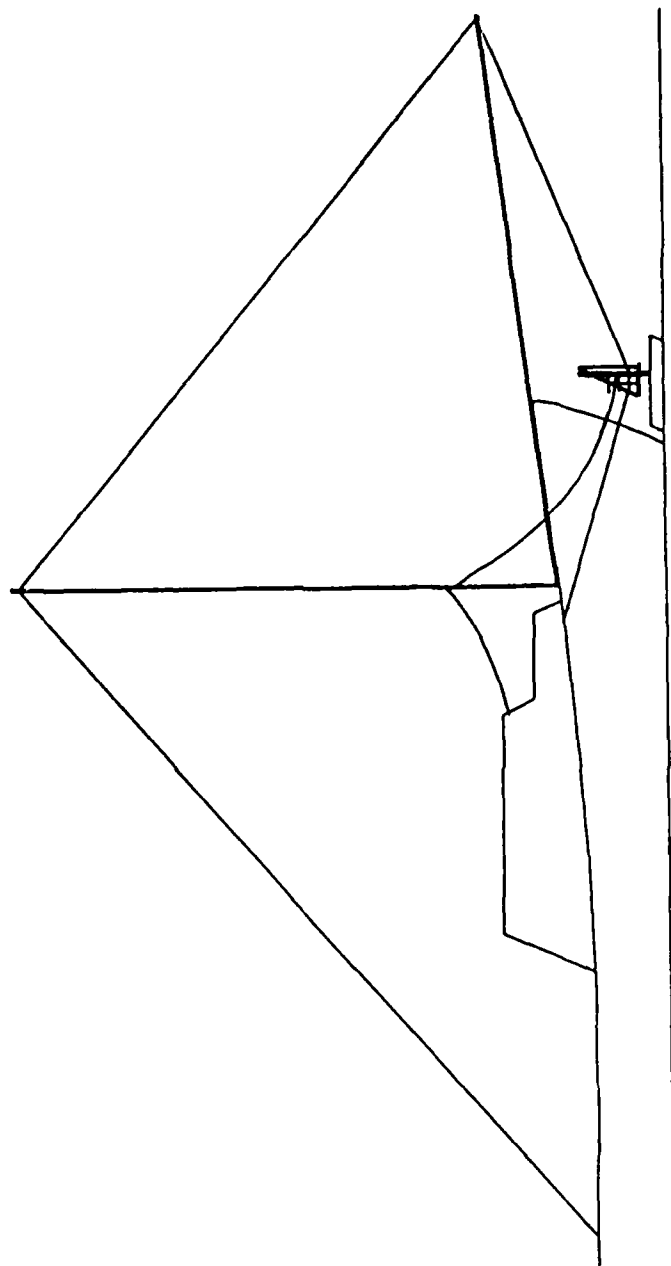


FIGURE 2

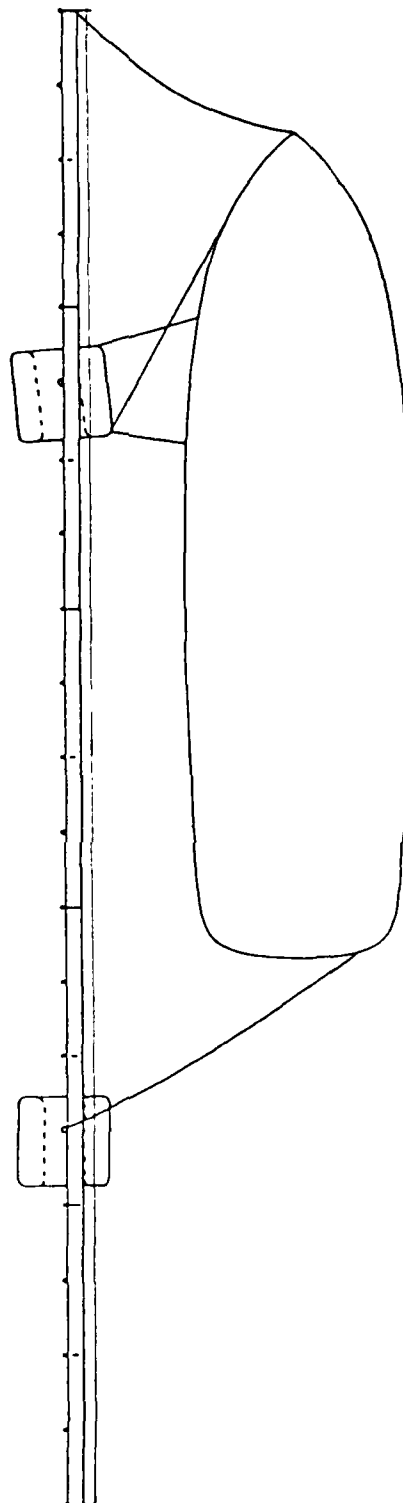


FIGURE 3

## A NEW GENERATION PORTABLE ECHO SOUNDER

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### BIOGRAPHICAL SKETCH

Bradford L. Keen is an electrical engineering graduate of Louisiana State University. He has been affiliated with Odom Offshore Surveys since 1975. After serving in the field as party chief on pipeline and archaeological surveys for several years, Mr. Keen joined Odom's Research and Development Department and returned to school, receiving his B.S.E.E. in 1980. He is currently a design engineer in the R and D group whose function is the development and production of marine survey electronics systems. Mr. Keen is a member of ISA.

### ABSTRACT

In recent years hydrographic survey technology has developed a need for a new generation of echo sounder. Surveys have become more sophisticated, expensive, and requirements more stringent. Hydrographers dealing with inland waterways now require the sophistication, accuracy and versatility of large digital oceanographic sounders while maintaining the portability, price, and ease of operation of the analog sounders of the past. A small, medium priced echo sounder has been designed that meets these criteria. The efficient use of microprocessor circuitry and state of the art thermal plotting has produced a precision digital echo sounder with all of the versatility of the oceanographics systems while remaining small and simple to operate. Sounders of this type will soon be a standard tool for inland waterways hydrography.

### INTRODUCTION

In the past, most echo sounders were strictly analog oriented machines that usually incorporated a moving stylus type chart recorder. They were inexpensive and filled the needs of surveyors. Today surveys are rapidly moving to automation and greater demands are being made on all equipment. Data requirements have become more stringent and a digitized depth record has become almost mandatory. Many new manufacturers have joined the industry pioneers in efforts to produce equipment to meet these demands. As a result there are now several formidable echo sounders on the market whose precision and versatility far surpasses previous generations. These echo sounders have proven their value in oceanographic surveys and have found some use in inland waterways work. There are many applications however, that although needed, the use of these sounders are severely restricted because of physical size, power requirements, complexity, and economics. In inland waterways work there is a need for a portable, moderately priced echo sounder

that can be battery operated, yet can provide the features of the oceanographic sounders. To make the design task even more interesting, the unit should be simple to use and must require a minimum of maintenance.

#### CHART RECORDER

The familiar moving-stylus type recorders have several disadvantages. The mechanical complexity and the many moving parts require a considerable amount of maintenance for proper functioning. Also, the system timing and chart accuracy is dependent to a large degree on the chart mechanism. Temperature, humidity, and power variations affect the mechanical linkages and timing, therefore the chart must be monitored and operator adjustments made periodically to insure optimum chart accuracy and consistency. The chart paper used with these systems has preprinted scale grids and the operator is limited to specific views of the water column. The operator is also required to make any annotations of job information or significant parameters by hand on the chart.

The new generation echo sounder utilizes a fixed-head thermal recording device that virtually eliminates all of these problems and provides many features that were never before possible. The actual printing mechanism consists of a nonmoving printhead containing hundreds of thermal "dots" which are heated precisely at the proper time to print the chart. The thermal recorder contains its own microprocessor to control the printing functions as well as its own quartz crystal controlled time base to maintain accurate chart speed. The only moving parts in the recorder are the motor and roller assembly which moves the paper across the printhead. The chart feed roller is driven by a precision, processor-controlled stepper motor. This mechanism is accurate, dependable, and requires a minimum of maintenance. Unlike moving-stylus type recorders, the chart and motor timing has no effect on the depth measurement accuracy; it only affects the speed at which the paper is advanced. Another major advantage of this type of recorder is that it accepts blank thermal paper. All scale grids and other chart features are generated by the unit, opening the door to endless chart formatting capabilities. The recorder also has the capability to print annotations containing parameters of interest (velocity constant, digitized depth, draft, etc.) at event marks as well as provisions for printing a descriptive header at either end of the records. These annotation abilities free the operator from having to write on the chart by hand. Thermal records do need to be safeguarded against extended exposure to bright light or excessive heat to preserve record print quality during storage.

A very significant result of having the chart scale defined by the unit is that the operator can tailor the chart to his specific needs. He can choose the chart center and edge limits depending upon the view of the water column he desires; showing the entire column from surface to bottom, or any specific portion of it. The sounder automatically

annotates the chosen scale so the chart range in use is never in question. The ability to compress or expand the chart range gives the operator essentially "zoom" control over the chart area. A useful application of this is the ability to observe bottom features in great detail by viewing only the water column in the immediate vicinity of the bottom. Figure 2 illustrates the use of this feature. In this example the bottom is shown in detail and it is possible to use the chart to show the exact relationship between an uncovered pipeline and the seafloor. A similar application would be in obtaining a detailed view of questionable construction failures.

Another innovative feature that, in most cases, eliminates an operator function is automatic scale change. As the bottom rises or falls out of the range of the chart, the unit automatically changes to the appropriate scale grid and prints the new scale values on the chart. Adjacent scales are provided with an overlap so there is no data gap and no bouncing back and forth between scales. This feature again allows detailed bottom viewing while also covering a very wide range of depths without operator adjustment.

#### ANALOG CIRCUITRY

In the process of designing an echo sounder, the first critical section to consider is, of course, the analog circuitry. This circuitry handles the transmission and reception of the transducer signals and is the heart of any echo sounder. In an effort to keep this section on the same technological level as the digital circuitry, state of the art analog techniques have been applied resulting in the performance and dependability necessary for a precision sounder while maintaining the size and power efficiency desired. The design has also resulted in the capability to be easily adapted for a wide range of transducer frequencies. Board sets are available that are tuneable over both the 18 to 50 kilohertz range as well as the 150 to 250 kilohertz range to cover a wide variety of survey requirements.

A multistage amplifier design incorporating both automatic gain control (AGC) and time varying gain (TVG) forms an extremely sensitive receiver section to handle the return pulses from the transducer. After amplification of the return pulses and filtering out unwanted frequencies, the signals are applied to a level detector which outputs a four line, magnitude based signal for plotting on the chart and processing by the digitizer section.

The driver and transmitter circuitry utilizes state of the art control and power devices to generate a very precisely controlled transmit signal at high power levels. These devices allow the generation of the high level signal while still maintaining a very high degree of power efficiency. The driver incorporates a unique feature that automatically adjusts the transmit power level to optimize the return signal. This feature has proven very practical in cases where the bottom rises or falls off rapidly. When this

happens the transmit power level increases or decreases as required to maintain the return signal at a useable level without ringing or dropout. Therefore the boat can traverse from deep to shallow water or vice versa with no operator adjustment to the echo sounder to maintain a consistent return signal level.

#### MICROPROCESSOR TECHNOLOGY

The concept of a new generation of echo sounder is based totally on the innovative and efficient use of microprocessor technology. The new design utilizes two microprocessor chips to control the functions of the sounder circuitry and the thermal chart recorder. Both microprocessors are eight bit devices whose performance and dependability have been industry proven. The chart processor controls the heating of the printhead dot array and the stepper motor that advances the paper while the main processor handles all of the operator features, the transmission and signal measurement, the digitization of the depth values for the displays and serial output, and the generation of chart parameters. The microprocessors utilize programs stored in internal memory (EPROMS) to accomplish all of these complex functions in an extremely short period of time. The majority of features in the unit would be physically and economically impractical if not impossible, without the application of state of the art microprocessor technology.

It should be noted that while the new echo sounder allows the user an unprecedented freedom to tailor the unit to his changing job requirements, it is amazingly simple to operate. All automatic functions can be altered or overridden by the operator when required. On power up, the sounder is pre-programmed with standard values, that in most cases, do not have to be altered. If the operator does wish to change any parameter then he has to change only those he is concerned with. He does not have to reprogram the entire set of values. The parameter values can be altered very quickly by the operator in a simple, straightforward procedure by simply setting a switch to the proper function and pushing a button to change the number shown in the display to the desired value. Once entered, the values are retained until the unit is turned off.

One of the seemingly simple tasks the processor must perform is the conversion of the bottom return signal to a numerical depth value for the displays and for output to a computer or data acquisition system. This job is actually far from simple. The processor must first examine all of the returns and decide which is the true return from the bottom. Once this is decided it must lock onto it and track it over a wide range of depths and maintain tracking through very steep or rapid slopes. It must also measure the elapsed time from transmission to receipt of return pulse and apply the sound velocity and various other factors to obtain a value for depth in the desired units (feet, meters, or fathoms). This digitized depth value must be consistent with the depth as scaled off on the thermal chart. Through innovative application of technology, the new generation echo sounder can maintain bottom lock over even the most



adverse riverbed or seafloor terrain and produce a consistently accurate digitized depth value.

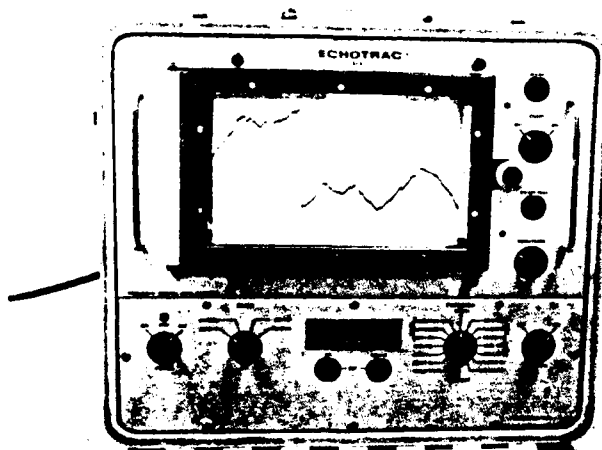
#### SUMMARY

ECHOTRAC<sup>tm</sup>\* is indicative of a new generation of precision portable echo sounders. Compact, d.c. powered, and moderately priced, it offers an array of features made possible by application of state of the art technology. It is a mechanically simple tool that performs amazingly intricate tasks. By eliminating complex mechanical assemblies and keeping parts count to a minimum, routine maintenance is greatly reduced. The extensive chart annotation and automation of critical functions makes the operation of the unit virtually "hands off", which, in many cases, reduces the number of survey personnel required on the boat.

As in the case of any new equipment development, all of the "bells and whistles" are irrelevant unless the unit offers an improvement from a data quality/survey efficiency/economic point of view. ECHOTRAC<sup>tm</sup> (as well as competitive units that are sure to follow) meets this criterium by:

1. Providing extremely accurate, consistent, and fully annotated data which simplifies and speeds up post survey data analysis;
2. In most cases eliminating the need for the constant attention of an operator, freeing him for other tasks and often reducing the number of required personnel;
3. Helping streamline survey time requirements when integrated with an automated data acquisition and positioning system.

#### ILLUSTRATIONS



ECHOTRAC<sup>tm</sup>.

\*ECHOTRAC<sup>tm</sup> is a trademark of Odom Offshore Surveys, Inc.

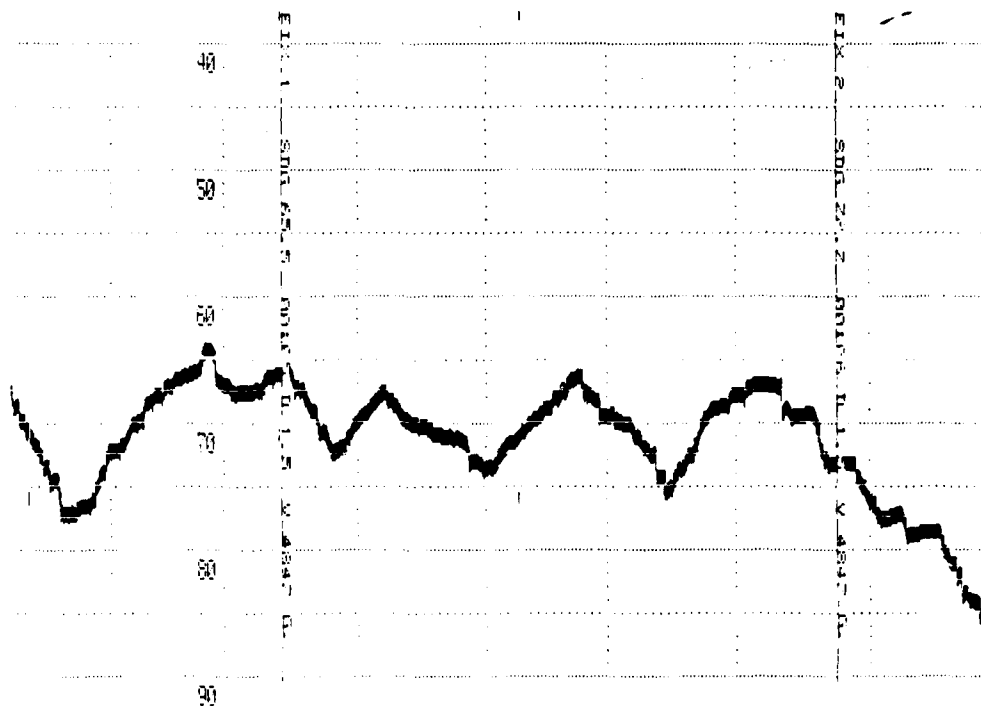


Figure 1. Sample of chart annotation.

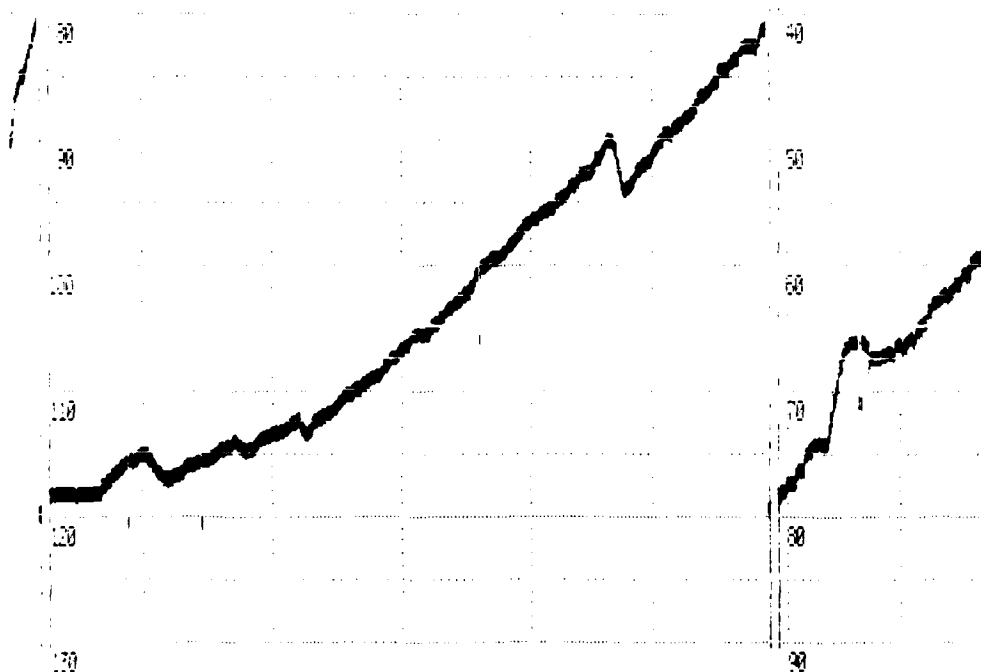
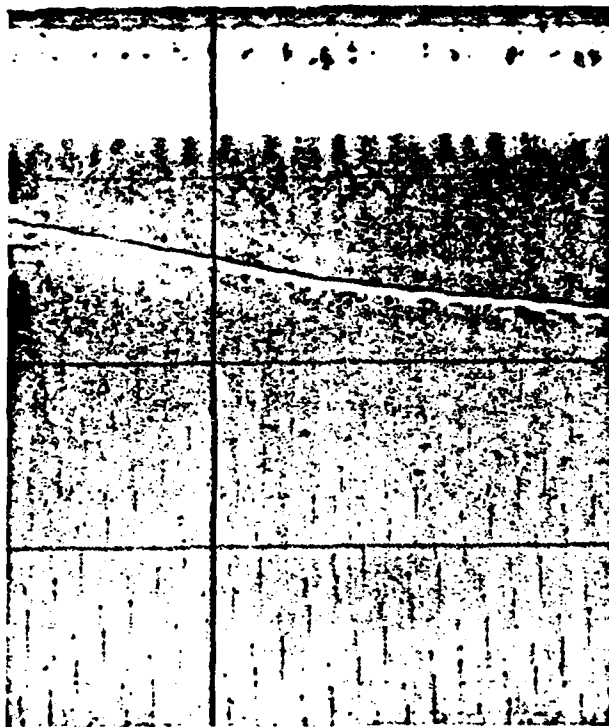
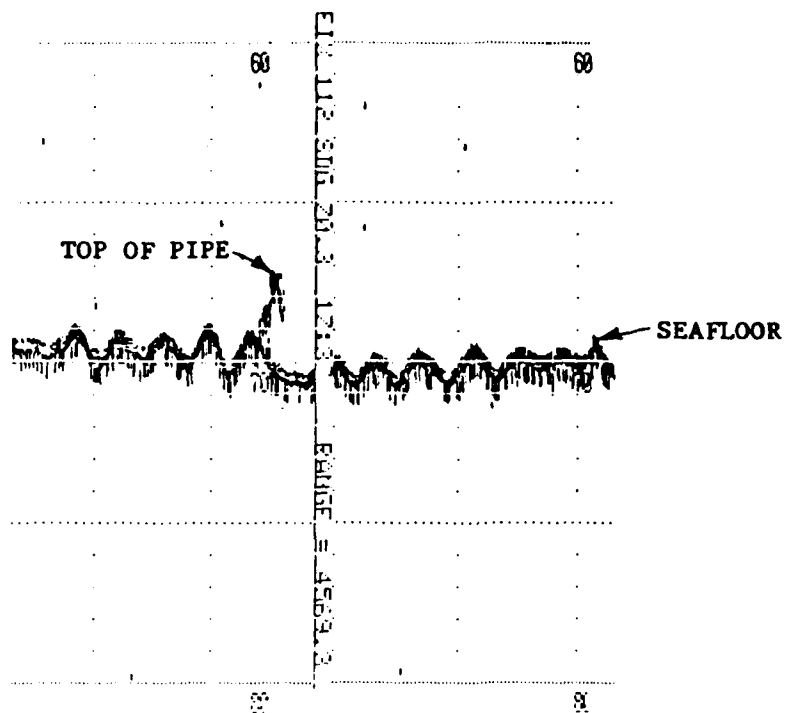
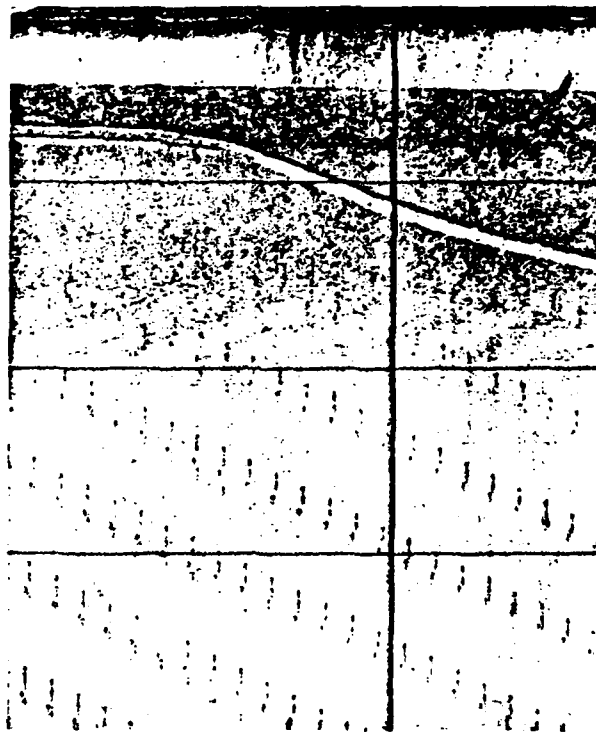
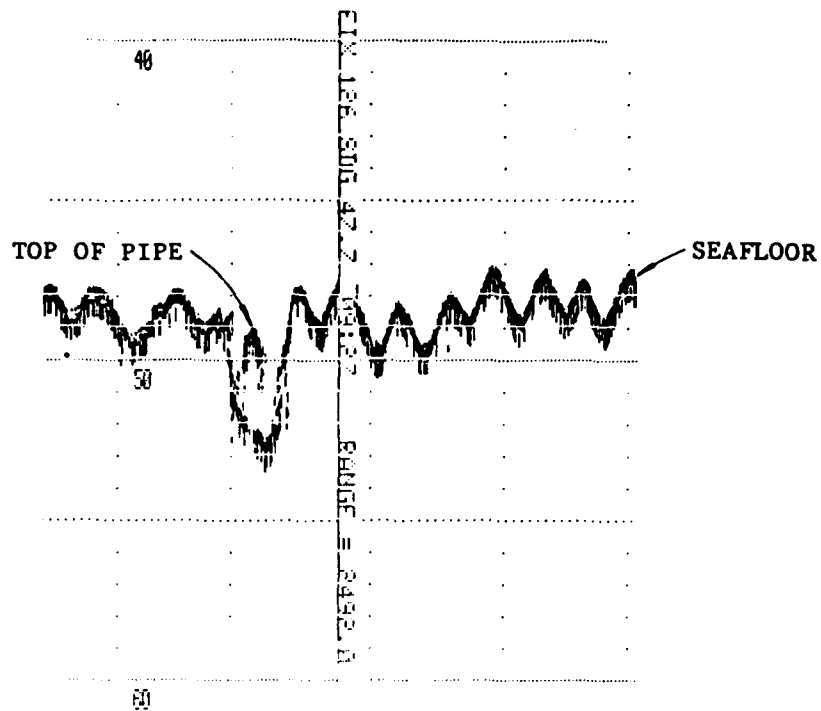


Figure 2. Example of automatic scale change.



4569

Figure 3. ECHOTRAC<sup>tm</sup> and side-scan sonar records of 36" pipeline.



2492

Figure 4. ECHOTRAC<sup>tm</sup> and side-scan sonar records of 36" pipeline in trench.

SESSION 11: HYDROGRAPHIC SWEEP SYSTEMS



George Downing  
WES  
Chairman

*Speakers*



William Allcock  
Kansas City District



Don Pryor  
NOAA



H. F. Wentzell  
Krupp-Atlas



E. B. Nielsen  
Navitronic  
(No Paper)

SESSION II  
HYDROGRAPHIC SWEEP SYSTEMS

Summary

Information on four different suppliers of hydrographic sweep systems were presented. A fifth supplier presented information on a proposed design.

Costs of sweep systems range by a factor of more than 10 between a simple 4-transducer Raytheon sweep system and a 36-transducer Krupp system.

When considering hydrographic systems, the selection process should include an evaluation of transducer scan area.

MISSOURI RIVER  
16 TRANSDUCER CHANNEL SWEEPING SOUNDING SYSTEM

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BIOGRAPHICAL SKETCH

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ABSTRACT

A constant accurate profile of a river bottom can be obtained through equipment found aboard the hydrographic survey boat, "Dakota." The combined Ross and Motorola System is a single, integrated positioning/sounding/profiling system. The system will take 16 or more simultaneous soundings every second complete with the coordinates of each sounding imprinted upon a magnetic tape that can be placed directly into a computer. Through computer programming, navigation charts, contour maps, constant profiling both graphically and numerically, and cross sections in any scale can be acquired. This system enables the Kansas City and Omaha Districts to sound the channel for navigation and profile for hydrographic information more quickly and with greater accuracy than in the past.

INTRODUCTION

The Kansas City District Dredging and Channel Reconnaissance Programs on the Missouri River are from its mouth at St. Louis to River Mile 500 at Rulo, Nebraska. Kansas City District's responsibility is to see that the navigation channel remains open.

At the last Hydrographic Survey Conference held in Wilmington, North Carolina, during December 1979, Wayne Dorrough of the Omaha District presented a paper covering the Multi-Purpose Channel Profiling System aboard the survey boat, "Dakota." The "Dakota" is used throughout the Missouri River. At that time, the "Dakota" had two separate systems installed on board.

One system that most Districts are familiar with is the Motorola Mini-Ranger II, an Automated Positioning Determination System, consisting of the basic operator terminal, tape recorder, depth sounder, plotter, and track indicator. Since many Districts utilize this system, this paper will be primarily an update on profiling equipment.

After the newness and related installation problems encountered on two different boats were corrected, the Motorola equipment has performed amazingly well with few problems.

The second system aboard the "Dakota" and the system this update covers is the Ross Laboratories Channel Sweeping/Profiling System. The Ross System has the capability of obtaining highly accurate, closely-spaced hydrographic survey soundings along a path approximately 90-feet wide. This system is particularly useful in channel sweeping operations, before and after dredge surveys, and bottom or bed-load studies. The system's electronic equipment consists of a 200 KHZ ultrasonic transceiver, two 3.5 degree transducers, hull-mounted, and fourteen 10 degree transducers, strutpod-mounted, and various other hardware items that allow the transmitted signals to be received by individual receiving amplifiers where they are suitably processed, and then converted (digitized) to digital, Binary Coded Decimal (BCD) depth data. These data are displayed and used in several ways to provide maximum detail and readily useable information. The depths, along with other information, position, time, coordinates, etc., may also be recorded, on magnetic tape, for later computer processing into scaled hydrographic survey charts, contour charts, cross sections, and in any other manner as users' requirements dictate.

#### OPERATIONS

The boat has two booms hydraulically operated, each having seven transducers, spring loaded to avoid being broken off during survey operations. When the boat moves from location to location, the booms are in the vertical position. When the booms are lowered into the operating position, the transducers are approximately 6 feet apart allowing the boat to cover the 90-plus feet in width.

Since the last conference, we have interfaced the Motorola and Ross equipment. What this means is that we have a positioning, channel sweeping/profiling system capable of collecting and recording more information than we can use or probably need for general survey information. We soon learned the equipment had the capability of furnishing so many signals on to our magnetic tape that by the time the tape was processed through the computer and a printout was made on a standard 1-inch to 400-foot survey chart, we were plotting soundings on top of each other. From this, we realized we had to determine the recording interval on the magnetic tape to be plotted. We accomplished this by synchronizing the two systems' time intervals in the computer programming. The time (hour, minute, second) was preset into the Ross and Motorola equipment. When the two systems are energized, the clocks are manually started at the same instant, or as close as our present needs require (less than a fraction of a second). Recordings are then obtained at one second intervals in both systems. With less than one second time error, it is estimated that travelling at about a rate of 7 miles per hour would have less than a 10-foot error in position, which is well within the tolerance of the positioning equipment and our needs. This time interface is the last item yet to be interfaced between the two systems.



A computer program was then developed by the Kansas City and Omaha Districts ADP to merge the two tapes into one file, and compute the position of each transducer, assuming the booms are perpendicular to the trackline of the boat. We have found overlying soundings resulting from yawing of the boat and overlapping tracklines. Also a slight depth error occurs when the center-of-gravity is shifted aboard a round-bottom boat. Although these errors are negligible for most practical purposes and applications.

The merging of the tapes was accomplished by simply comparing the times that were recorded and, when a time match was found, that position was used to compute the remaining transducer locations.

With all the problems encountered to date, we realized we have a piece of equipment that will give us a graphic picture of what is taking place on the bottom of the river. With shoals and other obstructions, many times missed using conventional methods, and through historical observations, we realized that the Missouri River frequently has a continuously moving bed. It can be visually observed and felt by a sounding pole moving downstream adjacent to a stationary boat or a dock. This material is soft enough that a sounding pole will work itself through the material, like a false-bottom type situation. Until we acquired this equipment, we had no idea what this movement consisted of or what it looked like. We now know that this moving bottom material is similar in appearance to sand dunes in the desert.

**Studies.** The Kansas City District has been conducting a propwash study using a converted Navy Landing Craft Medium (commonly known as LCM). The LCM has a baffle plate across the stern to direct this propwash. During the last conference in Wilmington, Mr. Charles Wyatt from the Kansas City District discussed this study. The profiling equipment has been extremely valuable in analyzing the results of propwashing obtained. Since the last conference, we have modified this LCM from the original two-plate configuration to a configuration having a single plate similar to the wast boat operated by the Portland District. Due to circumstances this past season, we have been unable to completely finish testing either the LCM (due to lack of a suitable location) or the survey boat, "Dakota," as she partially sank at her mooring early in the 1981 season. We are unfortunate in that we started assembling our equipment on an old boat. During equipment installation, the watertight bulkheads were compromised and, when a rubber exhaust boot overheated and burst, the boat partially sank. We managed to raise her, remove all of the electronic equipment, wash it down per the manufacturers instruction, and blowdry the equipment using hair dryers. This has been a lesson in how not to acquire and equip a survey vessel. The equipment has since been repaired, reinstalled, and operated with minor inconveniences. We thought we would have considerable problem with corrosion, but, to date, it has been negligible. If problems of major importance do occur, we will send the equipment to be commercially dried. During a 4-day period in October, while conducting additional propwash studies, the equipment was utilized by performing before, during, and after surveys of the propwashing operations.

Samples of Operations. The attached charts are representatives samples of operations conducted. They indicate the survey results direct from the equipment plus what can be accomplished through computer programming.

Chart 1. This chart is of the analog printout in profile showing the results of each of the transducers (like having 16 individual soundings). You can see the sand dune effect previously mentioned.

Chart 2. This chart is the digital printout of the same 16 soundings. In addition, the solid dark lines are from having the contour printout mode energized. This chart shows how easily cross sections can be made. When offsets are run, the computer programming can cross section any width required. We have run before and after dredge surveys and computed yardages with our program. We were unable to locate some results of this computation in order to furnish this chart. It is similar in appearance to the cross sections and yardage computations from the Motorola Mini-Ranger equipment.

Chart 3. This chart indicates the same soundings with the traditional method of contouring the same area.

The remaining charts are examples of data with different scales applied and different options of the contouring program. For information purposes, the program used is a CAL COMP GPCD 2.

Chart 4. This is a printout of the unedited seven track magnetic tape file direct from the Ross equipment. The amount of information available can be readily seen.

Chart 5. This is the same Ross file edited; the time indicated ties the two systems together.

Chart 6. This chart is from the Motorola Cassette file. (1) The top line identified by "x" has the beginning and ending coordinates of the track line, an offset capability, if required, and a draft correction. (2) the second line "y" has an altitude factor, if required, and the transponder location coordinates. (3) The third line has time, coordinates of the boat at that time, the maximum depth, average depth, and minimum depth, and a tide factor correction, if required.

Chart 7. This chart is representative of the Ross and Motorola file merged giving file, time, coordinates, and depth.

Chart 8. This chart is the X-Y-Z file. From these two charts, the next chart is arrived at.

Chart 9. This chart is an actual contour map of our Gasconade Harbor Facility at Missouri River Mile 104.5, at a 1-inch to 400-foot scale.

Chart 10. This is the same area plotted numerically from the same information.

Chart 11. This is the same area plotted at 1-inch equals 50-feet scale. The multiple uses of this equipment can be readily seen.

#### ACKNOWLEDGEMENTS

The author wishes to express his thanks for assistance to Richard W. Adrian, Kansas City District, Automated Data Processing, and Joe Volpert, Omaha District, Surveys.

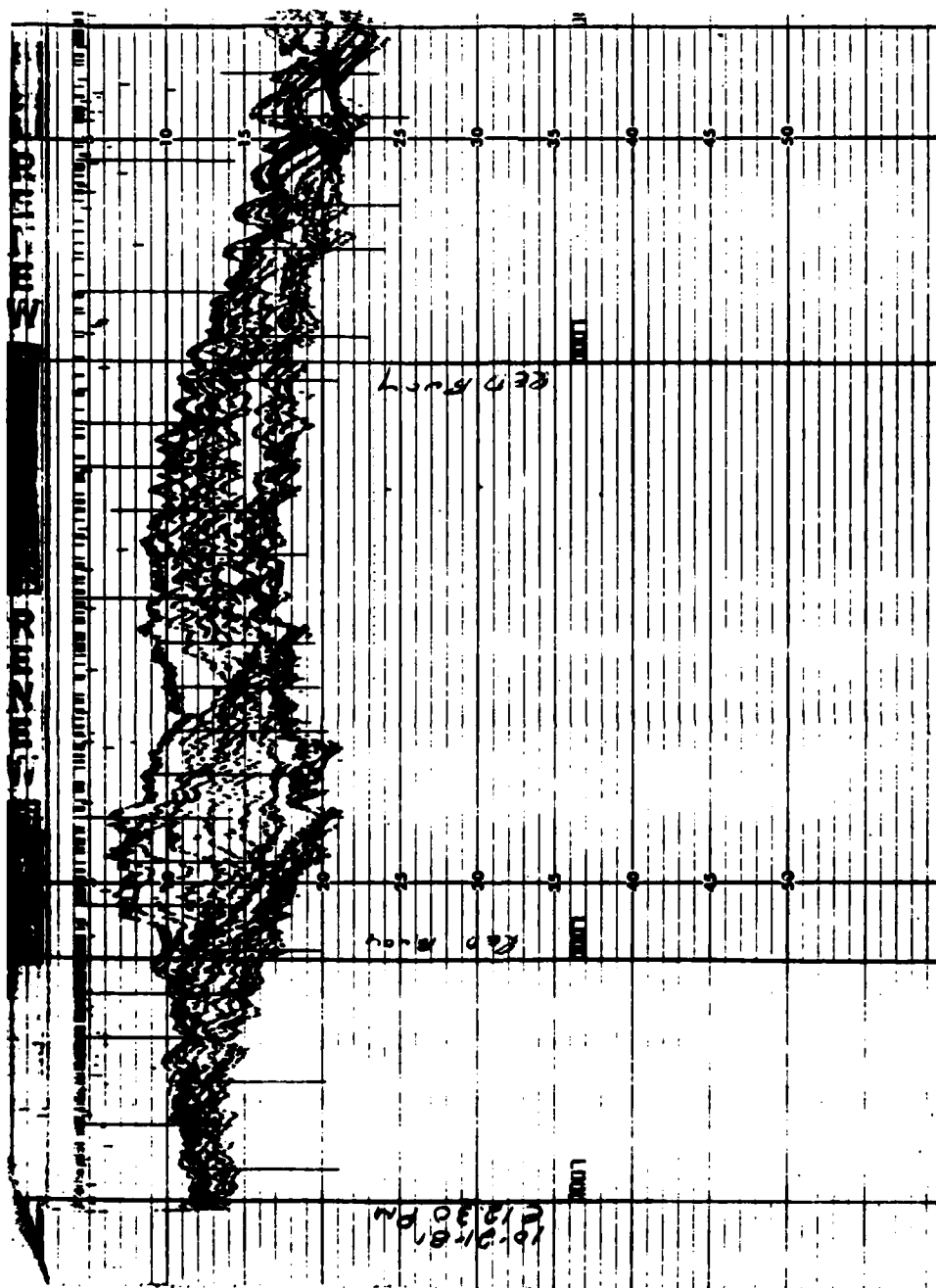


CHART NO. 1. ANALOG PRINTOUT IN PROFILE



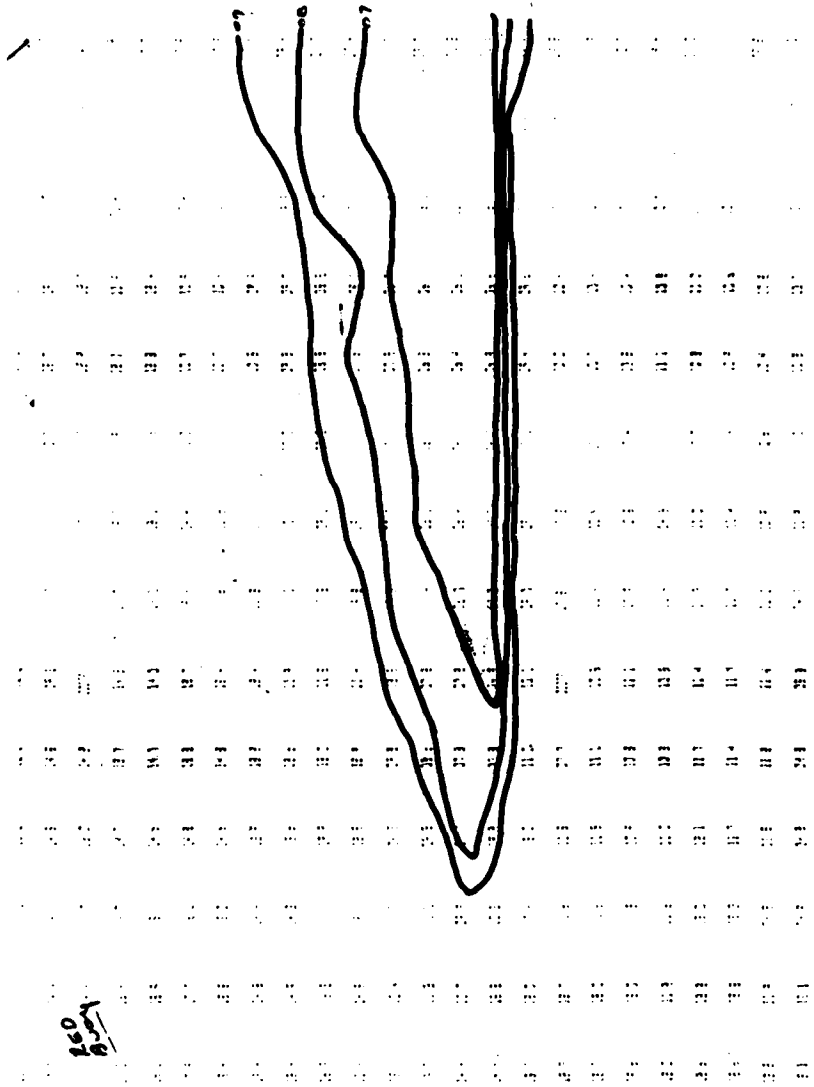


CHART NO. 3. SOUNDINGS WITH TRADITIONAL CONTOURING



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030000007089
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050930010535
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070000342109
080002985291
090000342354
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130300340790
140302985380
150300342025
160502985690
170500340790
180502985355
190500342885
004.4 104643 0001 092281
000.4 001341 104647 0001
04.3 06.3 08.8 10.4 11.6 11.4 11.2 11.8 12.1 13.4 15.4 15.6 14.4 15.0 15.8 13.6
004.3 001310 104652 0001
04.7 07.9 10.1 11.6 12.1 11.7 11.2 09.8 11.2 12.5 14.3 15.8 15.8 15.5 15.5 14.5
002.5 001283 104657 0001
05.0 08.1 10.7 11.5 11.7 11.8 11.9 11.4 10.9 12.4 13.9 15.7 16.1 15.0 16.8 14.8
000.9 001260 104702 0001
06.9 09.8 12.2 12.4 11.7 11.6 04.5 11.7 11.8 12.5 13.0 14.1 14.8 14.5 15.5 14.1
004.3 001226 104707 0001
08.6 11.1 11.7 12.6 1 *INTERRUPTED*
STOP
*TERMINATED*
N)

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# CHART NO. 5. SAME ROSS FILE EDITED

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A 01 2985978 342109 8 0 02 2986038 343548 10 0 03 2985291
B 00 0 0 0 0 00 0 0 0 0 00 0
C 00 0 0 0 0 00 0 0 0 0 00 0
D 00 0 0 0 0 00 0 0 0 0 00 0
E 2985978 342109 2985291 342354 2986038 343548 2985310 343238 29856
F 2985690 340790 2985355 342885 0 0 0 0 0
G 0 0 0 0 0 0 0 0 0
H 0 0 0 0 0 0 0 0 0
I 0 0 0 0 0 0 0 0 0
J 0 0 0 0 0 0 0 0 0
K 0 0 0 0 0 0 0 0 0
L 0 0 0 0 0 0 0 0 0
M 0 0 0 0 0 0 0 0 0
N 0 0 0 0 0 0 0 0 0
O 0 0 0 0 0 0 0 0 0
P 0 0 0 0 0 0 0 0 0
X 0 2985690 340790 2985380 342025 0 0 320 1.000000093
Y 19 2985978 342109 8 .0 2985291 342354 10 .0 0AB
10146142 2985668 340789 4.7 3.6 .1 .0 1
10146143 2985671 340796 4.3 2.3 .1 .0
10146148 2985667 340827 6.5 3.8 .4 .0
10146153 2985653 340858 4.8 4.0 .2 .0
10146158 2985641 340889 6.2 4.5 .4 .0
10147103 2985632 340921 7.6 4.4 .2 .0
10147108 2985623 340951 9.1 5.6 .1 .0
10147113 2985610 340981 9.3 6.6 2.0 .0
10147119 2985601 341010 8.4 5.4 .1 .0
10147123 2985588 341041 8.1 4.4 .1 .0
10147128 2985583 341070 7.3 4.8 .1 .0
10147133 2985576 341098 8.7 5.7 2.5 .0
10147138 2985572 341126 12.0 6.7 .1 .0
10147143 2985560 341154 11.9 4.5 .1 .0
10147148 2985550 341180 11.4 5.4 .1 .0
10147153 2985539 341204 10.8 6.0 .1 .0
10147158 2985532 341231 8.5 4.6 *INTERRUPTED*
STOP
*TERMINATED*
N)CLEAR
5 FILE(S) PROCESSED.
N)

```

# CHART NO. 6. MOTOROLA CASSETTE FILE COMPUTER PRINTOUT

```

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030000007089
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050930010535
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070000142109
0800002985291
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180502985355
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T104647 2985667 340827 0001
04.3 06.3 08.8 10.4 11.6 11.4 11.2 11.8 12.1 13.4 15.4 15.6 14.4 15.0 15.8 13.6
T104652 2985653 340858 0001
04.7 07.9 10.1 11.6 12.1 11.7 11.2 09.8 11.2 12.5 14.3 15.8 15.8 15.5 15.5 14.5
T104657 2985641 340889 0001
05.0 08.1 10.7 11.5 11.7 11.8 11.9 11.4 10.9 12.4 13.9 15.7 16.1 15.0 16.8 14.8
T104702 2985632 340921 0001
06.9 09.8 12.2 12.4 11.7 11.6 04.5 11.7 11.8 12.5 13.0 14.1 14.8 14.5 15.5 14.1
T104707 2985623 340951 0001
08.6 11.1 11.7 12.6 13.1 12.3 04.3 05.3 06.1 11.5 11.9 12.8 14.0 13.9 13.9 13.7
T104712 2985610 340981 0001
08.5 11.4 12.1 13.0 12.4 12.8 13.2 12.0 12.0 11.5 11.4 12.6 13.9 13.9 14.9 13.8
T104717 2985601 341010 0001
08.3 11.3 12.5 13.0 12.9 12.5 13.4 12.6 12.0 04.5 11.7 12.0 13.2 13.7 15.3 14.2
T104722 2985588 341041 0001
07.6 10.5 12.3 12.7 13.2 13.1 13.9 12.6 12.8 13.1 12.5 12.1 11.9 11.2 13.0 12.8
T104727 2985583 341070 0001
06.0 09.2 11.2 12.6 12.9 11.9 13.1 13.0 13.1 12.3 11.8 11.9 11.7 11.4 12.0 11.2
T104732 2985576 341098 0001
07.0 10.0 11.6 13.1 13.6 13.5 14.0 13.1 12.8 12.8 12.4 12.3 11.9 12.0 12.9 11.8
T104737 2985572 341126 0001
10.1 12.8 14.1 14.5 14.2 14.1 14.8 13.2 13.0 13.2 12.9 12.8 12.5 11.9 12.9 11.7
T104742 2985560 341154 0001
12.3 13.6 13.4 14.1 14.7 14.6 15.6 13.1 12.6 12.3 12.2 04.4 04.5 04.3 12.8 11.9
T104747 2985550 341180 0001
11.9 12.2 13.2 14.2 14.1 13.8 14.9 13.1 12.4 12.2 11.7 11.8 11.6 12.0 12.6 11.3
T104752 2985539 341204 0001
04.3 12.9 12.3 13.3 13.3 12.8 13.4 11.3 13.2 12.2 13.1 12.1 11.7 11.7 12.6 11.9
T104757 2985532 341231 0001
07.7 11.1 12.2 12.7 13.2 13.2 13.9 05.3 13.8 13.2 12.4 12.6 12.6 12.3 12.3 04.3
T104802 2985528 341257 0001
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T104817 2985513 341292 0001
06.4 10.4 11.6 12.4 13.5 13.5 14.1 13.5 13.5 13.0 13.3 12.9 11.8 11.8 12.3 11.8
T104812 2985507 341322 0001
06.4 09.7 10.5 11.8 12.1 11.5 12.2 12.4 12.1 11.7 13.3 11.4 12.6 12.1 12.4 12.1
T104813 2985507 341323 0001 092281
06.4 0 10.8 11.3 10.7 11.6 12.1 0 *INTERRUPTED*
STOP
*TERMINATED*
N>

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CHART NO. 7. ROSS AND MOTOROLA MERGED FILE



74001 M400/74 PONCA BEND TO RULO BEND  
 0. 92281 740012985690. 340790.2985380. 342025. 400. 200.RI.  
 101770. 397480.1017390. 400015. 1273.  
 MAX, MIN 2985959 342903 2985289 340778

2985624	340718	4.3	1
2985609	340847	4.7	1
2985597	340878	5.0	1
2985588	340910	6.9	1
2985579	340940	8.6	1
2985566	340970	8.5	1
2985557	340999	8.3	1
2985544	341030	7.6	1
2985539	341059	6.0	1
2985532	341087	7.0	1
2985528	341115	10.1	1
2985516	341143	12.3	1
2985506	341169	11.9	1
2985495	341193	4.3	1
2985488	341220	7.7	1
2985484	341246	5.8	1
2985469	341281	6.4	1
2985463	341312	6.4	1
2985460	341326	6.4	1
2985458	341340	6.0	1
2985448	341368	5.3	1
2985436	341397	4.3	1
2985429	341428	4.3	1
2985431	341458	4.3	1
2985429	341491	4.3	1
2985413	341521	4.3	1
2985391	341549	4.3	1
2985431	341590	4.3	1
2985396	341661	4.3	1
2985391	341690	4.3	1
2985380	341720	4.3	1
2985378	341748	4.3	1
2985370	341776	9.4	1
2985364	341805	9.0	1
2985357	341845	8.3	1
2985352	341876	6.9	1
2985352	341893	4.3	1
2985343	341949	7.6	1
2985343	341968	7.8	1
2985335	342010	7.8	1
2985341	342011	12.0	2
2985349	341969	11.2	2
2985349	341950	11.1	2
2985358	341899	9.2	2
2985358	341877	11.1	2
2985363	341846	12.8	2
2985370	341806	13.0	2
2985376	341777	12.5	2
2985384	341749	9.9	2
2985386	341721	13.4	2
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\*INTERRUPTED\*

STOP

CHART NO. 8. X-Y-Z FILE

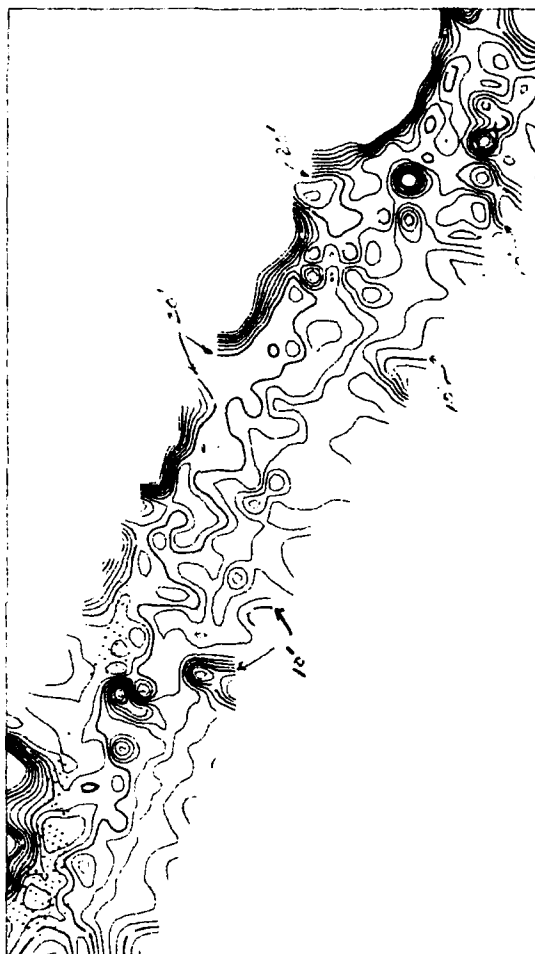
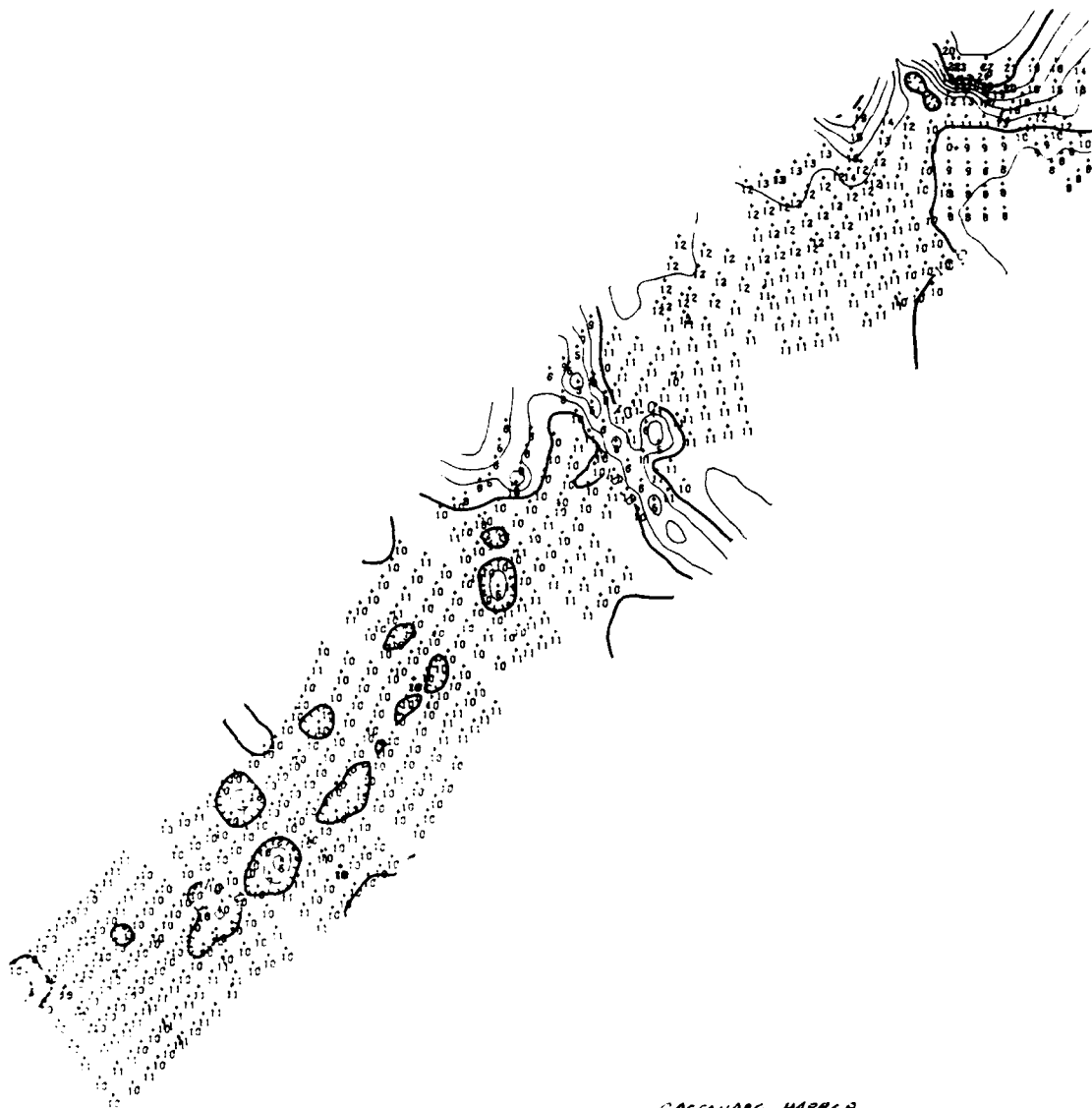


CHART NO. 9. ACTUAL CONTOUR MAP RESULTING FROM  
CHARTS 7 AND 8



GASCONADE HARBOR

CHART NO. 10. SAME AREA PLOTTED NUMERICALLY AT 1 IN. = 400 FT

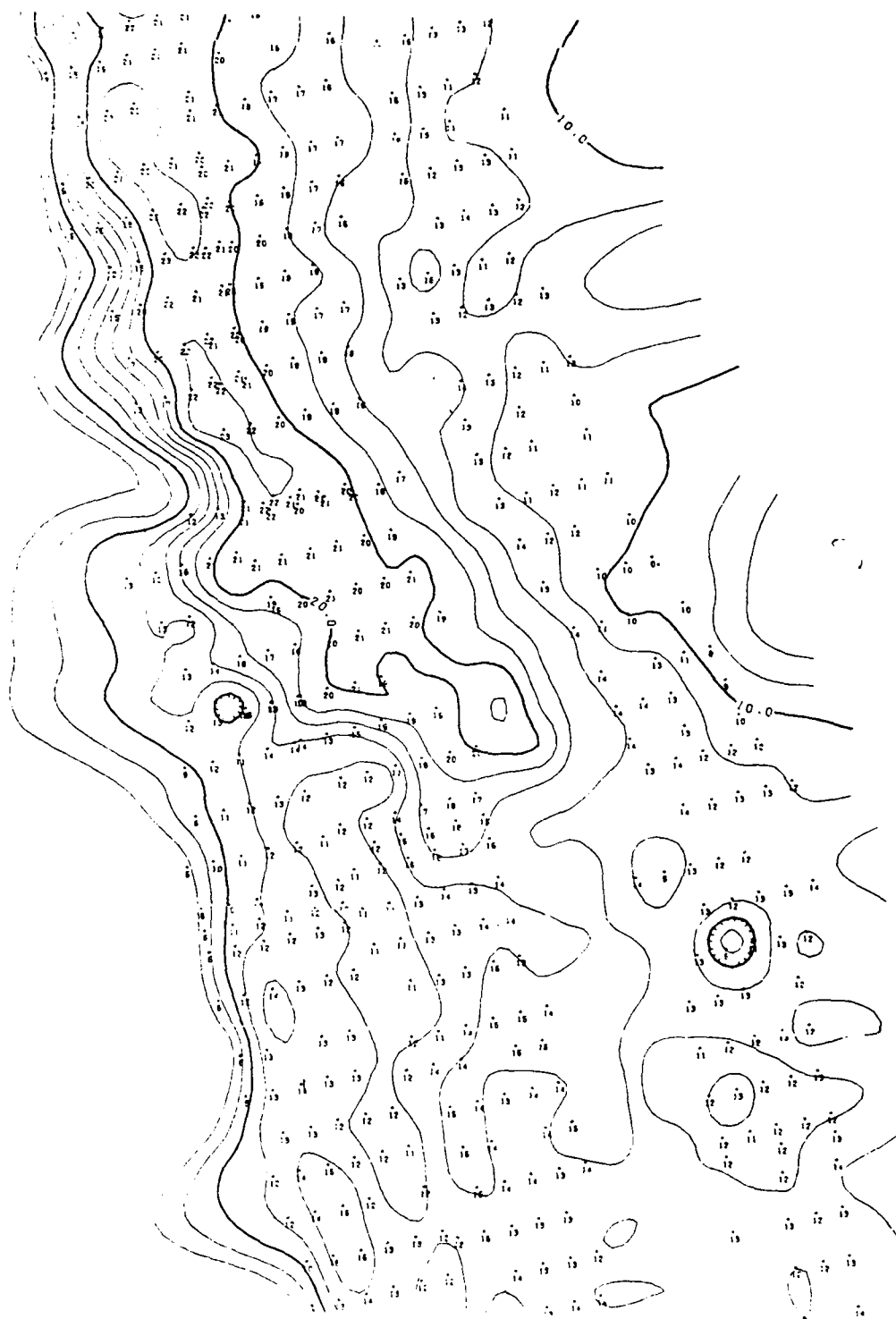


CHART NO. 11. SAME AREA PLOTTED NUMERICALLY AT 1 IN. = 50 FT

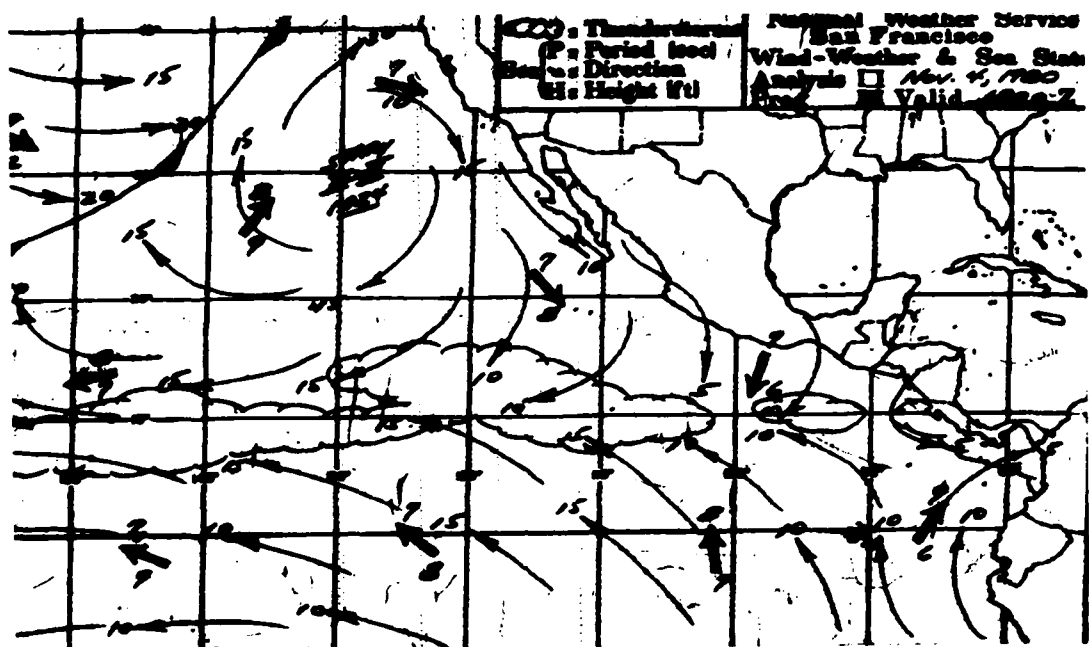


CHART NO. 12. NATIONAL WEATHER SERVICE PROGNOSIS



CHART NO. 13. NATIONAL WEATHER SERVICE SURFACE ANALYSIS

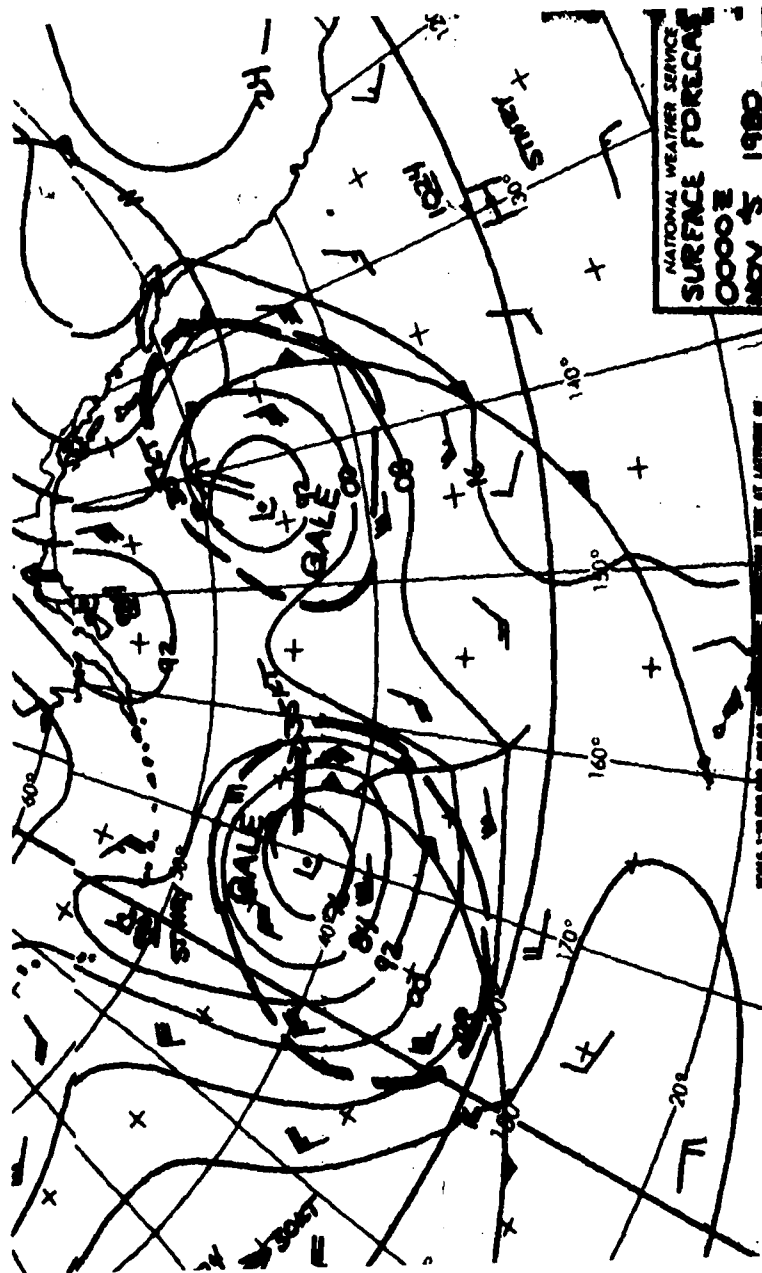


CHART NO. 14. NATIONAL WEATHER SERVICE SURFACE FORECAST

PERFORMANCE CHARACTERISTICS OF THE BATHYMETRIC  
SWATH SURVEY SYSTEM AND THE HIPPY SHIP MOTION SENSOR

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BIOGRAPHICAL SKETCH

Donald Pryor is an electrical engineering graduate of the Massachusetts Institute of Technology with a masters degree from the University of Maryland. From graduation in 1968 until 1978 he worked at the Naval Surface Weapons Center in White Oak, MD., in the development of underwater ordnance. Since 1978 he has been with the Engineering Development Office of NOAA working on hydrographic systems development and the application of acoustics to oceanographic instrumentation. Mr. Pryor is a member of the IEEE and ASA.

ABSTRACT

The Bathymetric Swath Survey System (BS<sup>3</sup>) is a multi-beam hydrographic system for use in intermediate water depths. It provides a capability for rapid, detailed charting over a swath equal to 2.5 times the water depth. The system incorporates two novel sensors - the BOSUN sonar and the HIPPY ship motion sensor. This paper describes the results of tests on the HIPPY sensor as well as the overall BS<sup>3</sup>. Laboratory and field tests of the HIPPY showed that its performance met the requirements of an error budget established for the system. A series of tests were then conducted to assess both the accuracy and reconnaissance capability of the complete system. The accuracy was shown to meet international standards except in shallow water areas with soft bottoms and in deep water when the data came from the outer beams. The system clearly indicated a large shipwreck and rugged natural features but it could not reliably detect an object as small as a 24-inch triplane. Several small area surveys demonstrated the advantage in ship time and charting detail that this system offers over conventional, single beam depth sounders.

INTRODUCTION

The Bathymetric Swath Survey System (BS<sup>3</sup>) is a multi-beam sonar system designed to gather hydrographic data in water depths from 20 feet to 2000 feet. The multi-beam concept makes it possible to have complete coverage of bottom bathymetry in swaths of width roughly 2.5 times the water depth. The concept is similar to that of the Navy's SASS system and to the Sea Beam System which is now in use by NOAA, several universities, and other governments. The BS<sup>3</sup> differs from these deep water systems in that it is designed to provide the higher accuracy, faster data rates, and broader angular coverage required in intermediate water

depths. The system used by NOAA is the first and, at present, the only one of its kind.

The BS<sup>3</sup> gathers data from six data sources - the sonar, a heave-roll-pitch sensor, a positioning system, a tide measurement system, a gyrocompass and a sound velocity measurement device. Figure 1 is a block diagram of the system and a sketch of the sonar beam geometry. The sonar is the BOSUN system developed by General Instrument Corporation. It operates at 36 KHz and forms a fan of 22 acoustic beams each five degrees in width. Signal processing in the sonar extracts the slant range to the bottom for each of these beams. The heave-roll-pitch sensor is the HIPPY 120C developed by Datawell B.V. of the Netherlands. It uses a very long period pendulum as a stable reference from which to measure ship motion. Tide data is available either from real-time telemetry or from predictions. Positioning, heading, and sound velocity data are provided by conventional subsystems. Data from these sources are integrated through a Camac interface to a Digital Equipment Corporation PDP 11/34 minicomputer. The data is logged on magnetic tape for post-processing. During the survey a plot is generated showing the vertical depth and bathymetric contours for the shoaler side of the swath. In addition a position plot is produced showing the vessel track and the extent of swath coverage. The BS<sup>3</sup> is presently installed aboard the NOAA ship DAVIDSON. More complete descriptions of the system are provided by McCaffrey (1981) and Farr (1980).

Accuracy of the data produced is the most important performance characteristic. The BS<sup>3</sup> was designed to meet the requirements of the International Hydrographic Bureau. Hopkins and Mobley (1978) established an error budget for the system to reflect these international standards. Figure 2 shows how permissible errors were allocated among the data sources. Tests were designed to check performance of the HIPPY against this error budget. Following these HIPPY tests, a series of tests were conducted to characterize the performance of the complete system.

#### HIPPY 120C TESTS

The design of the HIPPY is based on technology developed for Datawell's Waverider buoys. An accelerometer and two coils are mounted on the bob of a pendulum inside a fluid sphere. The buoyancy is adjusted so that the natural period of the pendulum is very long - 120 seconds. The pendulum remains stable despite horizontal forces on it since these forces tend to be at higher frequencies. The acceleration sensed is, therefore, the vertical acceleration and the coils can sense roll and pitch with respect to other coils fixed to the instrument housing. An internal microprocessor filters and integrates the acceleration to provide the heave output.

Tests on the HIPPY sensor consisted of three phases - laboratory tests, tests with the unit mounted in a van, and tests aboard the ship. Details of these tests are covered in a NOAA technical memorandum (Pryor, 1981a).



Laboratory tests afforded an opportunity to observe the response of the HIPPY to simple, well controlled motions. The unit was mounted on a ferris wheel-like fixture which carried it through a precise amplitude heave with variable frequency. Figure 3 shows one of the frequency response plots obtained. This particular output is delayed from actual motion by 77.2 seconds. The delay permits processing the acceleration in such a way as to maintain accuracy over the broadest range of frequencies. It is accurate within three percent down to a period of only 30 seconds. Another output indicates heave in real-time but it is accurate down to a period of only 16 seconds. Dynamic roll and pitch responses were also measured. These responses are in real-time. They showed no frequency dependence and appeared to be accurate within the specified 0.1 degrees.

The van tests were designed to test the HIPPY response to horizontal accelerations. Sudden changes in speed or direction produce errors in the outputs because these motions disturb the pendulum used for a reference. The tests were done on an abandoned runway to minimize any actual roll, pitch, or heave. Accelerations were extreme by comparison with what would be expected aboard ship. The results were in reasonable agreement with theoretical predictions.

Shipboard tests were conducted off Cape Hatteras. The area was surveyed during calm conditions, found to be flat within one foot and marked with buoys. A data acquisition system was set up to gather data from the HIPPY and a Ross depth sounder. Figure 4 is a typical one minute sample of the data. Waves at the time had a significant height of about 1.6 meters with periods of about 14 seconds. The Ross depth measurements show peak-to-peak variations of about five feet. (The gap in the middle of the record is caused by missed soundings.) When the Ross depth is corrected with the real-time heave, an obvious low frequency residual remains but the peak-to-peak variations are reduced to two or three feet. When corrected with the delayed heave the peak-to-peak variation is less than one foot and the rms variation is reduced to 0.15 feet or 1.8 inches. All such intervals which were not corrupted by a change in mean depth showed an rms variation or standard deviation of less than 0.31 feet. The error budget allowed a standard deviation of 0.3 feet. Normal turns did not produce large enough effects to be separated from other errors. Low frequency response did not prove to be a limitation in working with the delayed output though the real-time output often showed very large errors with slow motions.

Thus these tests showed the HIPPY to be an entirely adequate instrument for motion correction of hydrographic data. Though it was developed with the RS<sup>2</sup> requirement in mind only its physical size limits its applicability to other hydrographic systems.

### BS<sup>3</sup> TESTS

Tests of the BS<sup>3</sup> were designed to determine its accuracy and its reconnaissance capability. The tests took place in April, 1981, at six different locations off the northwest coast of the U.S. Each location was chosen to provide a different dimension to the performance characterization. Tests and results are described in detail in another NOAA technical memorandum (Pryor, 1981b).

Accuracy was determined by examining the statistics of repeated soundings at the same location. The basic technique was to conduct a "patch test" in which the ship was run in a modified figure eight pattern as shown in Figure 5 over the desired test site a large number of times. Soundings from these runs were assigned to bins within a grid. Each bin was comparable in size to the footprint of the beams at that site. The variability of data from a particular beam was estimated from the statistics of soundings produced by that beam and assigned to a single bin. Biases of the outer beams were determined by using the center beam as a transfer standard. The center beam bias was determined with respect to a bottom mounted pressure sensor or to a conventional single beam echo sounder. (Note that the sonar actually forms a center beam with the starboard as well as the port transducers. Unless otherwise indicated "center beam" data was actually taken from the port center beam rather than the starboard or a combination.) Data from the conventional depth sounder was logged simultaneously with the BS<sup>3</sup> data for comparison with the center beam.

Figure 6 shows the results obtained at Cape Disappointment in water depths of about 100 feet. Nearly all the beams produced data which met the standard deviation goal to support international standards. The bias data indicates an uncompensated roll of 0.4 degrees presumably due to misalignment between the sonar transducers and the motion sensor. The mean depth reported by a conventional Ross depth sounder differed by 0.5 feet from the mean depth reported by the center beam of the BS<sup>3</sup> due to differences in draft, settlement, and squat parameters used to correct the soundings. When this offset and the roll bias are removed, the total error in the soundings (including both bias and variability at the 90 percent confidence level) was estimated to be less than 2.9 feet for all the beams. This meets the international standards. Further, the variability of the center beam data was approximately the same as the variability of data from the conventional system.

Tests in 2200 feet of water yielded results shown in Figure 7. The estimated standard deviations are within the allowable range for the central 14 beams of the swath. The bias data shows the same uncompensated roll as observed at the Cape Disappointment site. The variability of soundings from a 12 KHz single beam depth sounder was comparable to that of the center beam of the BS<sup>3</sup> and the difference between the mean depths reported by the two systems was again 0.5 feet. When the roll bias is removed the total error (again bias plus variability at the 90 percent

confidence level) for the central 14 beams meets the accuracy standard. The decrease in accuracy of data from the outer beams is an expected characteristic of a swath system and the performance observed exceeds the manufacturer's specifications.

Another patch test was conducted in Bellingham Harbor again in about 100 feet of water but this time over a very soft bottom. The variability of the data was unacceptable both with respect to the standards and by comparison with the variability observed from a Ross depth sounder. This is presumably due to the sounding frequency and the type of estimator employed in the BS<sup>3</sup>. A fourth patch test was conducted over a steeply sloped area in the San Juan Islands. The data indicated reasonable performance but the rugged terrain introduces variability that cannot be separated from system inaccuracies. It was noted that the sonar tracking gates regularly had difficulty with one very abrupt terrace.

The reconnaissance capability of the BS<sup>3</sup> was examined in four tests which involved both natural and artificial features of varying extent. The tests were designed to assess the effectiveness of the real-time outputs as well as the quality of the post-processed data.

The first test was against a 24-inch triplane moored 12 feet above the bottom in Bellingham Harbor. This target provides a strong acoustic return but is of very small extent. Its presence was not detectable on the real-time contour chart. Examination of the recorded data showed that it returned at least one echo in eight of 17 passes. In order to be recognizable on the contour chart more than one return is required and, therefore, the target must be larger. A second test was over the wreckage of a 500 foot oil tanker in Rosario Strait. Figure 8 shows a perspective plot that was constructed from the sounding data. It provides a fairly detailed picture of the wreckage. Every run produced recognizable indications of the wreck on the real-time contour chart.

There were two tests of the system's reconnaissance capability versus natural features - in the San Juan Islands and Astoria Canyon. The test site in the San Juan Islands was one-half mile by one mile and contained three features with least depths of 180, 220 and 300 feet in general depths of 350 feet. The area was surveyed independently with a conventional system. Hydrographic officers were able to extract least depths and locations of features from the BS<sup>3</sup> real-time outputs that were consistent with the sounding plot from the conventional system. Twelve runs in the vicinity of the largest feature produced least depths that were consistent within  $\pm 2$  feet if the least depth was sounded by the central 14 beams. One-hundred percent coverage with the BS<sup>3</sup> required only half the time needed for the main scheme of the conventional survey. Astoria Canyon tests showed system performance over a rough bottom in deeper water. Figure 9 shows a contour plot generated from data obtained from three survey lines with 400 meter

spacing. There are three anomalies which appear as "bullseyes" and which apparently were caused by interference from the conventional depth sounder. Otherwise the chart appears to be accurate. Detailed bathymetry covering this five square mile area was produced from data obtained in less than two hours with the BS<sup>3</sup>.

#### SUMMARY

The HIPPY tests showed that that device meets the requirements for a vessel motion sensor to correct hydrographic data. The BS<sup>3</sup> tests indicated several aspects of overall system performance which require investigation and further development. These include excessive variability of data in areas of soft bottom and anomalies caused by acoustic interference and sonar gate loss. Post-processing software to edit the data for presentation on a sounding plot must be systematically analyzed. Verification and quality control procedures require attention. These matters will be addressed as NOAA makes transition from system development to operational use of the BS<sup>3</sup> over the next year. The tests have shown that the BS<sup>3</sup> has the potential to provide more complete coverage with less ship time than conventional single beam depth sounder systems.

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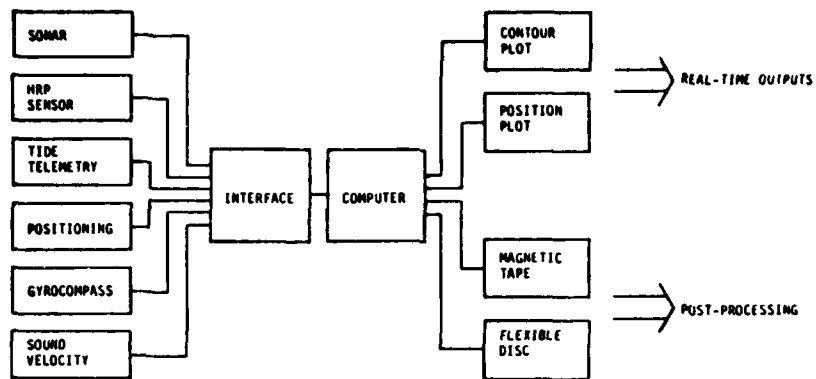


FIGURE 1A: SYSTEM BLOCK DIAGRAM

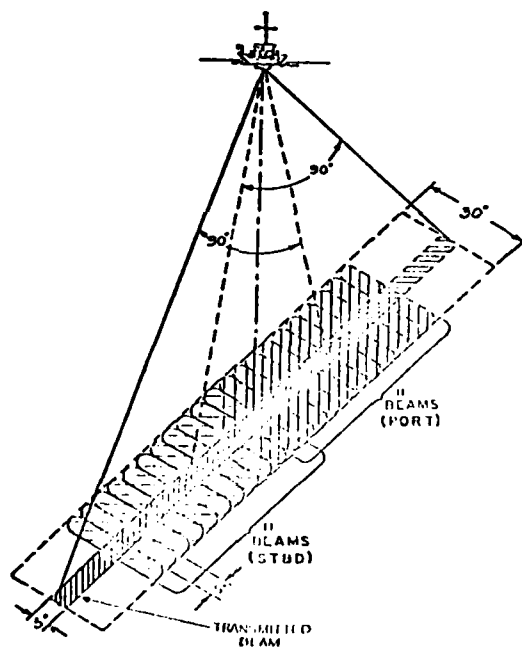


FIGURE 1B: SONAR BEAM GEOMETRY

## ACCURACY REQUIREMENTS

### ERROR BUDGET (1 σ )

SOURCE	FEET	METERS
Echo Return Time Error	.30 + .003d	.10 + .003d
Heave Error	.30	.12
Pointing Error	.003d	.003d
Tidal Error		
Zone Variation	.12 + .003d	.06 + .003d
Rounding	.06	.06
Sound Velocity		
Measurement Error	.002d	.002d
Zone Variation	.002d	.002d
Rounding	.06	.06
Draft		
Measurement Error	.12	.06
Time Variation	.30	.12
Settlement and Squat		
Measurement Error	.12	.06
Variation	.30	.12
Tidal Datum	.18	.06
<hr/>		
Standard Deviation of Depth Measurement	.67 + .006d	.28 + .006d
90% Confidence Interval for Depth Measurement	1.1 + 0.1d	.5 + .01d

### INTERNATIONAL STANDARDS

DEPTH	ALLOWABLE ERROR	
0-20m	1.0	0.3
20-100m	3.0	1.0
>100m	1% of depth	

Figure 2. Accuracy Requirements

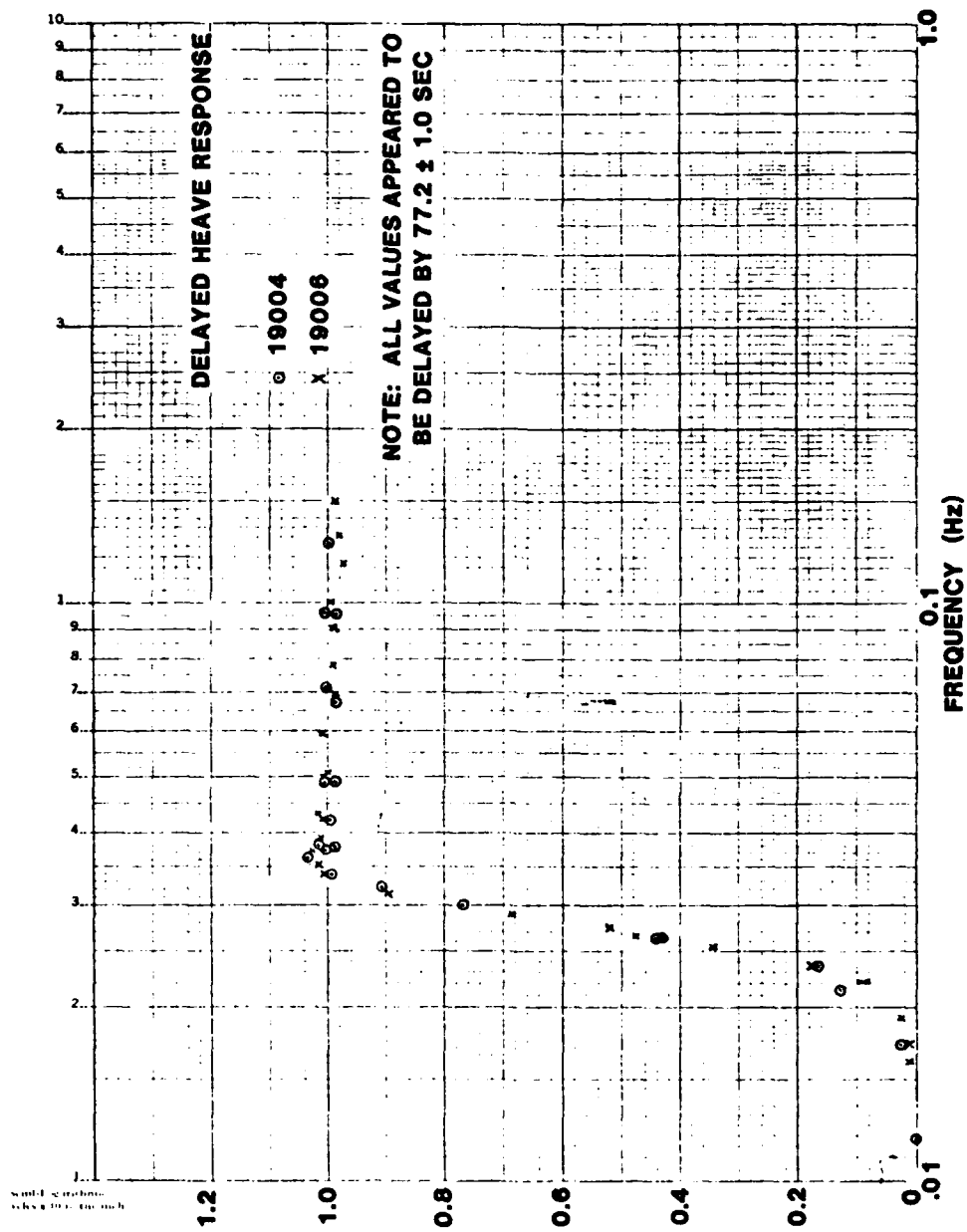


Figure 3. Delayed Heave Response





TYPICAL PATCH RUN IN  
SHALLOW WATER (~100 FT)

~1000 FT

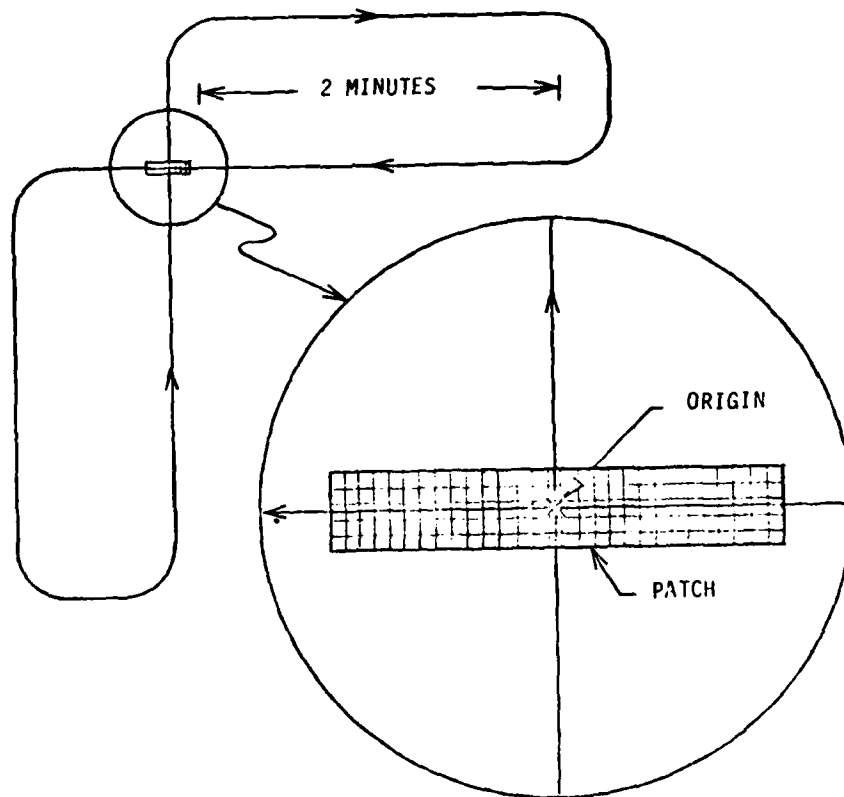


Figure 5. Patch Test Run

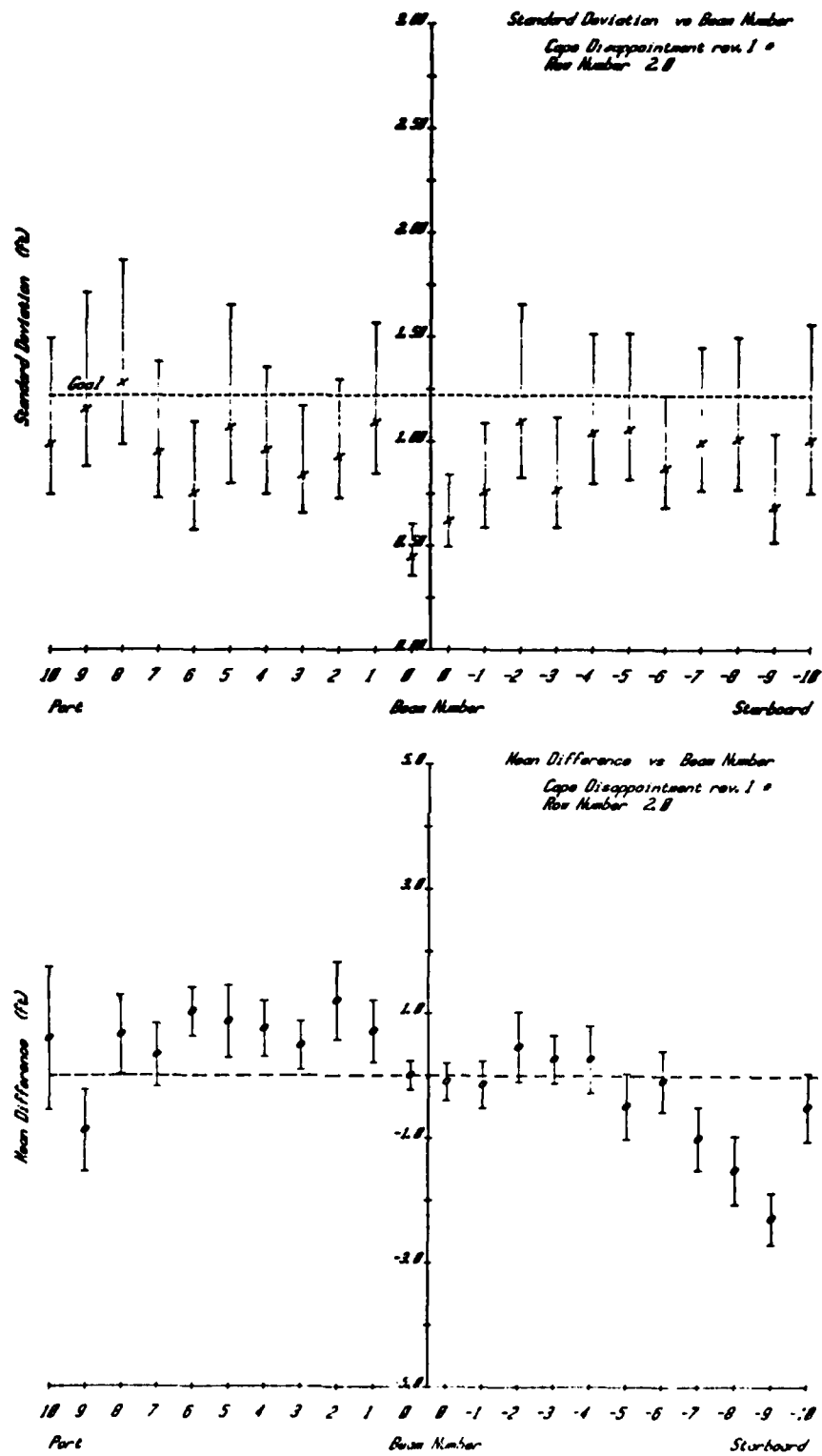


Figure 6. Cape Disappointment Patch Test Data

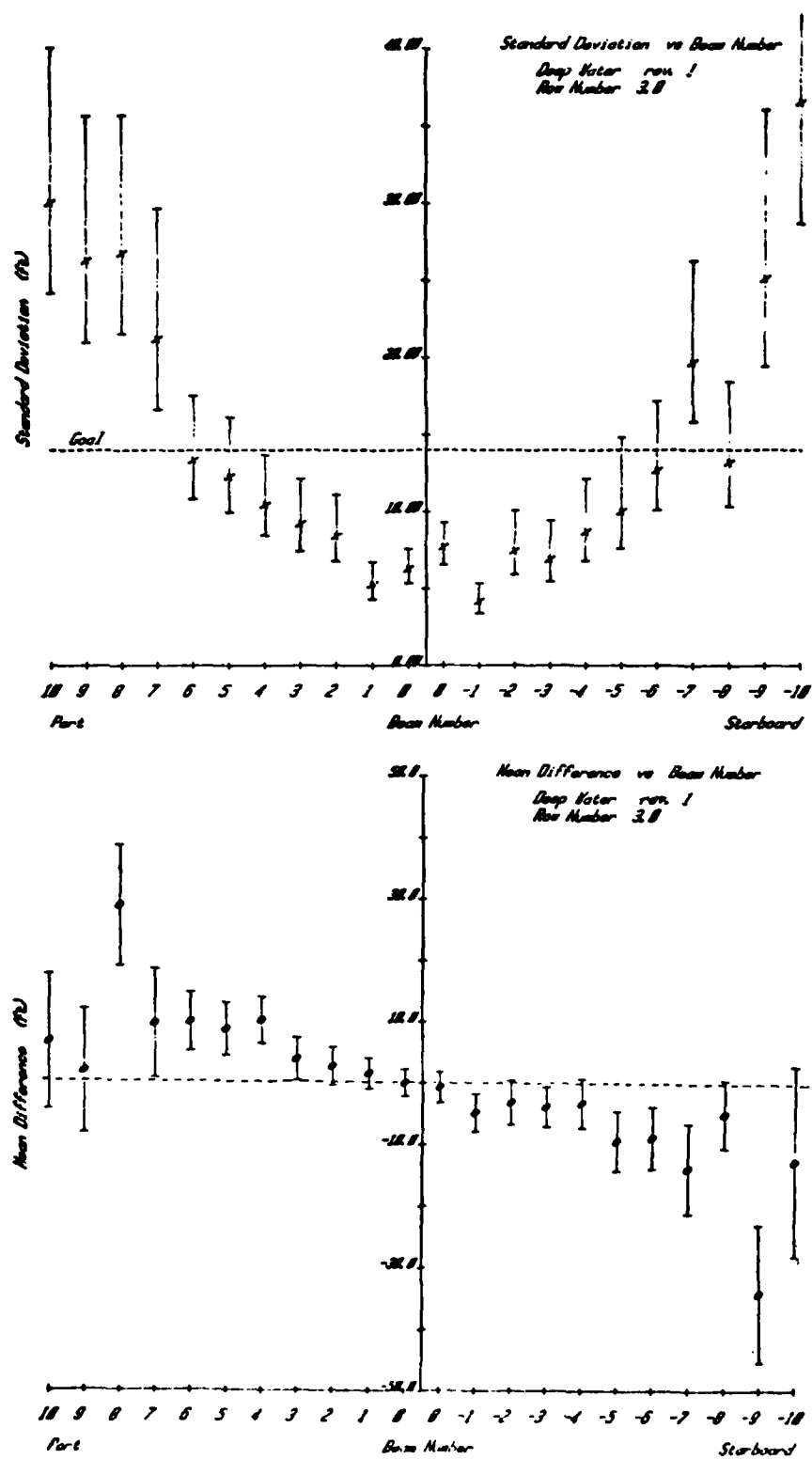


Figure 7. Deep Water Patch Test Data

SOUTH AMERICA  
 Date: 21-11-52  
 Ship: 21-11-52  
 Name: 21-11-52

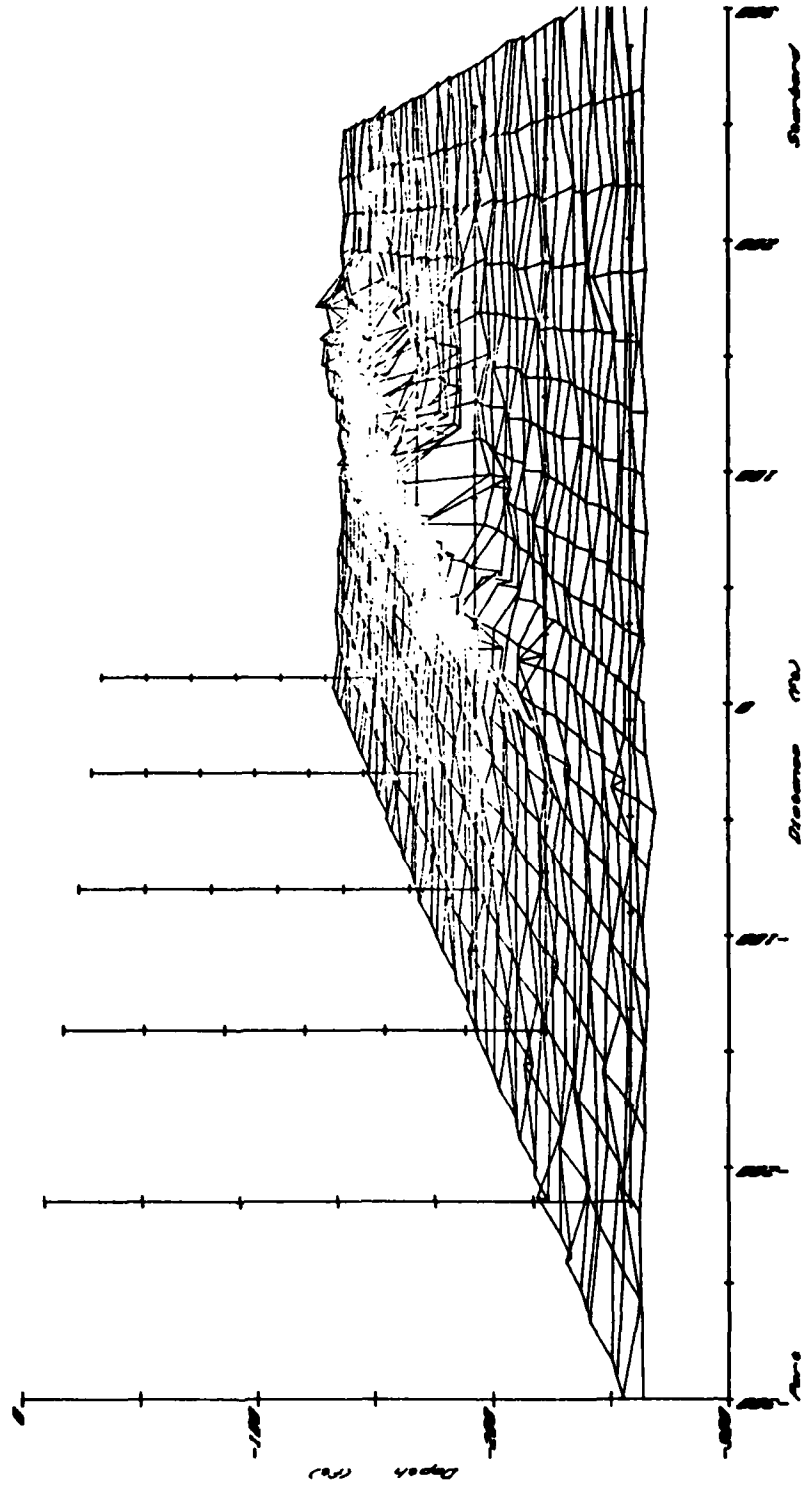


Figure 8. Perspective Plot of Wreckage

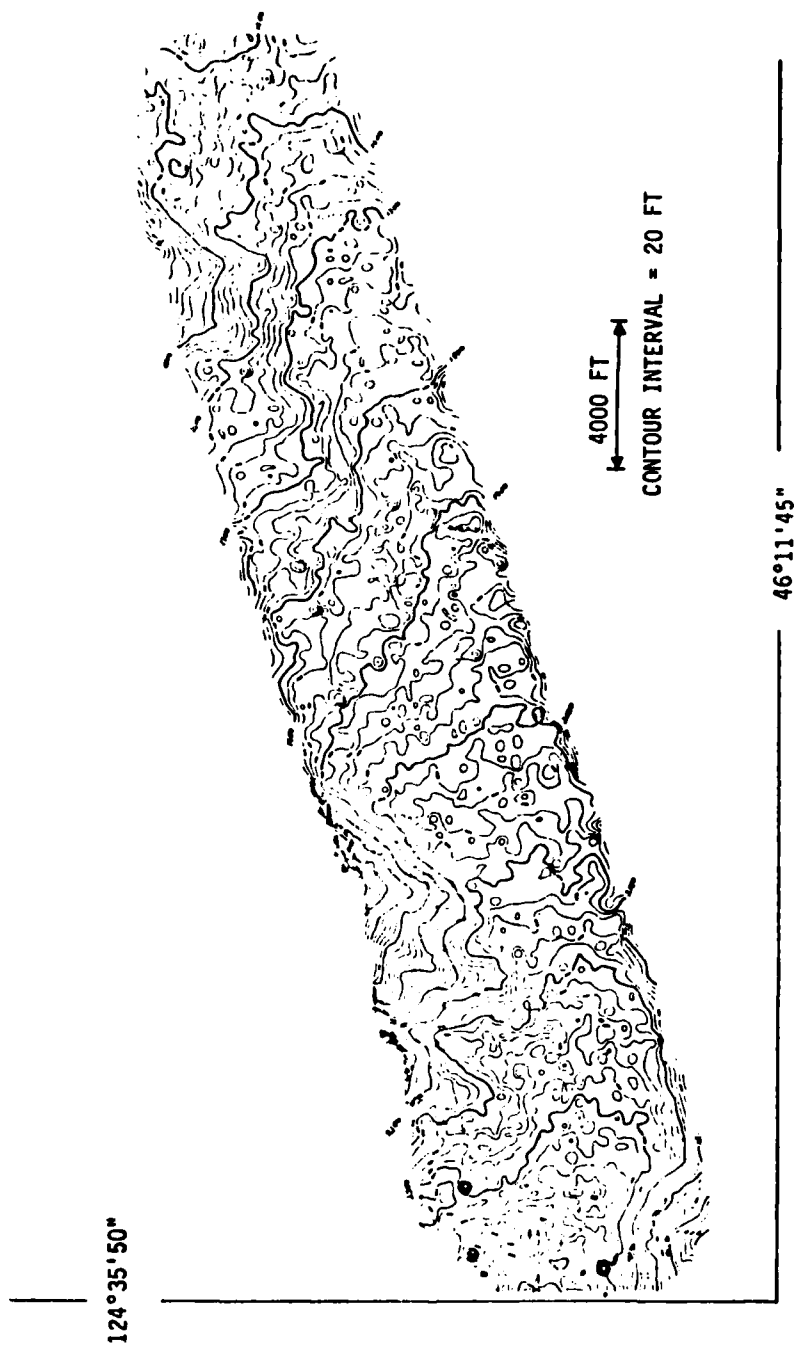


Figure 9. Bathymetric Contours - Astoria Canyon

## TOTAL BOTTOM MAPPING SURVEY SWEEP SYSTEM

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### BIOGRAPHICAL SKETCH

Hubertus F. Wentzell is Marketing Manager for Products and Systems for hydrographic and offshore applications. Since he finished his electronics studies in Bremen in 1969, his work has been related to hydrography. Mr. Wentzell is a member of the Hydrographic Society, London.

### ABSTRACT

Bottom Sweeping Systems are contributing to the safety of traffic in most of the main European waterways as well as in some harbours and inshore areas. Recent developments in system technology and the availability of appropriate position determination equipment make such systems ideal tools to carry out surveys both for safety surveillance and for hydrographic surveying. They combine the ability of gapless coverage of the bottom required for safety with the high depth measurement precision required for hydrographic applications. The economic benefits of systems able to cover a width of 150 feet with each survey track are self-explanatory.

The deployment characteristics and alternatives, the principle lay-out of appropriate survey vessels and the design concept of the electronic system are discussed, and samples of plots with raw and processed data are included.

### DEPLOYMENT CHARACTERISTICS AND ALTERNATIVES

When discussing surveying requirements it is of course the morphology of the bottom which has to be considered first. But also the position determination method which depends primarily on the topographical circumstances, and - not to be forgotten - economic tasks like rationalisation of the survey operations are important factors. Some examples:

### 1. Morphology (see fig. 1)

The fair sheets show an area where the river Elbe splits into a Northern and Southern arm. The upper sheet shows depth contour lines generated out of cross profile survey data. The lower sheet shows the same area, but the survey was carried out with a sweeping system ATLAS-BOMA 20.

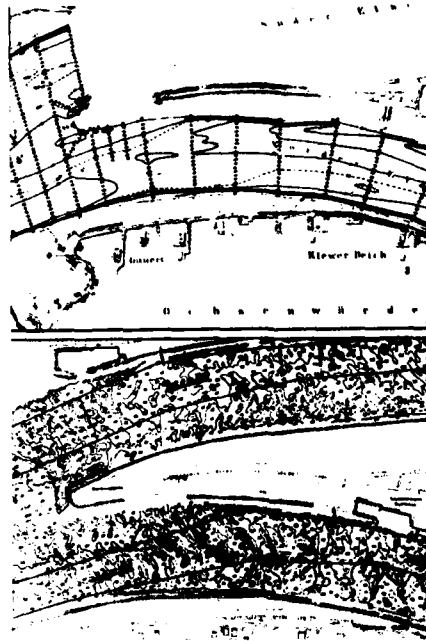


Figure 1. Comparison between cross-profile- and sweeping survey methods

This comparison shows clearly that it depends on the morphology whether cross profile surveys can be useful to determine the bottom structure.

Another example is the river Rhine near Bingen where the deepening or correction of the fairway can only be carried out through very exact blasting. Without the sweeping system ATLAS-BOMA 20 it would be very costly and time-consuming to find out whether and where boulders or shelves remained after blasting.

Both the morphology conditions of the river bed and the current velocity of the water may also influence the design concept of the survey vessel, i.e. whether the ultrasonic transducers can be installed in booms for a vessel to move in the ship's axis direction along the river or whether the transducers must be installed alongside the hull or in the keel for a vessel to move perpendicularly to its axis and across the river.

## 2. Economy

A river area with a length of 15 statute miles and a width of 300 feet has to be surveyed. Question: Which survey method is less time-consuming:

- a) a cross profile survey with a parallel track-distance of 100 yards, or
- b) a gapless sweeping survey with longitudinal tracks and 150 feet sweeping width?

(Assume an average speed of the vessel of 12 ft/sec. for longitudinal surveying and 8 feet/second for cross profile surveying.)

It is easy to calculate the result:

A survey vessel equipped with a Sweeping System carries out the same survey job in a considerably shorter time compared to the cross profile survey method - but gapless. In specific regions where - because of morphological conditions - the spacing between tracks must be closer or where additional longitudinal profiles have to be run, the ratio is even more favourable to the Sweeping System.

We all know that dredging work is costly. Inaccurate surveys in areas requiring frequent dredging, e.g. in rivers with much sediment transport, add their contribution to the dredging costs, for instance because of relatively large safety margins which have to be applied. An accurate and gapless sweeping survey system can, just by gaining dredging efficiency, recover its investment costs within a very short time.

## 3. Position Determination

The sweeping system can basically fulfil two different tasks, and a combination of these, with optimum results:

First, safety surveillance: The survey vessel runs long distances along the survey area (e.g. river or canal) and indicates without delay all hazardous depth areas for traffic warning or dredger guidance management.

Second, hydrographic surveying: Highly accurate and gapless depth information is obtained with an amount of information about the morphology of the bottom only comparable to the information provided by aerial photogrammetry.

For the first application, safety surveillance, only moderate positional accuracy is required, just good enough to identify the shoal areas, because the primary concern is not the accuracy, but the safety: not to overlook any hazardous spots within the traffic channel.



The second concern is the efficiency of the vessel in terms of covering a long distance in a short time. Position determination by optical means from shore and often also position determination by means of radar systems like Mini-Ranger or Trisponder are in many cases not possible because of the number of people or reference stations required on shore with all the associated logistical costs. If only safety surveillance is the task of the vessel, a sonar doppler log, specially designed for shallow water operations, can provide all information which must be acquired automatically to establish a moderately accurate position, but it does not need any active shore stations. Hydrographic surveys with sweeping systems require positional accuracies of the order of 3 - 10 feet to make use of the horizontal depth resolution the system provides. Today, only radio- or radar position determination systems with active reference stations on shore can give this accuracy. Also, for this survey method the economy of the operation counts. To enlarge the area covered by radar positioning, several reference stations can be placed along the river or canal, but still, depending on the meandering of the river and on the surrounding topography, zones of non-coverage remain. For such areas we are proposing the combination of sonar doppler navigation and radar position determination in one system. This may help to reduce the number of reference stations without loss of accuracy, while gaining full positioning coverage and redundancy.

#### LAY-OUT OF SURVEY VESSELS

As briefly mentioned above, basically two types of survey vessels are deployed for bottom sweeping systems: The first type of vessel (see figure 2 a) is designed to execute only longitudinal surveys. It is equipped with booms mounted on both sides of the vessel and which can be swung out and in quickly by means of hydraulic support drives.

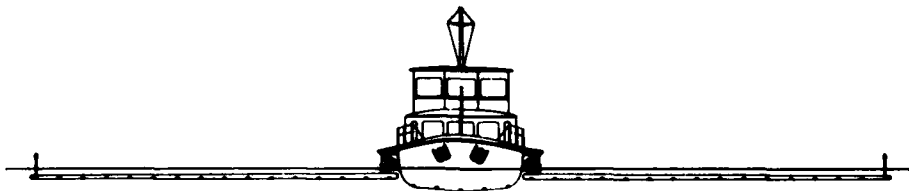


Figure 2a. Sweeping survey vessel with booms

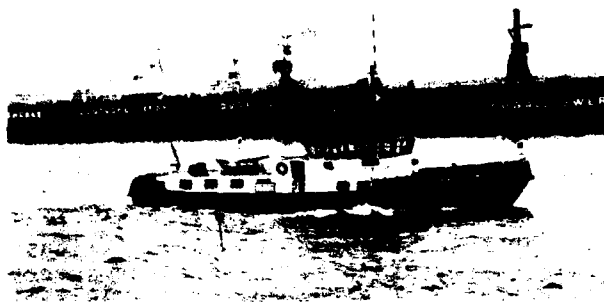


Figure 2b. Survey vessel "DEEPENSCHRIEWER II,"  
Hamburg Harbour

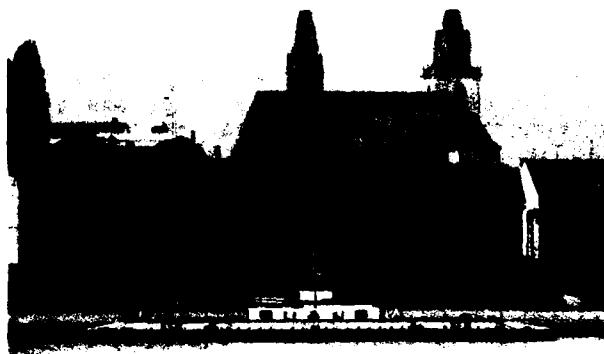


Figure 2c. Survey vessel "BINGERBROCK,"  
Rhine



Figure 2d. Total Bottom Mapping Survey Sweep  
System ATLAS-BOMA 20/ATLAS-SUSY 41

The shape of the booms is hydrodynamically neutral so that nearly no vertical force is generated at any speed of the vessel. Residual forces due to fabrication tolerances are compensated by means of small fins at the tips of the booms. This design concept offers the advantage that not only the booms are horizontally stabilized in the water - they in turn also stabilize the survey vessel in its roll axis.

The ultrasonic transducers are installed in the booms and, between them, in the hull of the vessel. We have realized booms of length 60 feet each, so that the total sweeping width can be as wide as 150 feet depending on the beam width of the survey vessel. The speed of such vessels, with the booms extended, can be as high as 10 knots. A vessel of this type typically has a length of about 80 to 100 feet.

The second type of sweeping survey vessel (see fig.3a/3b) is designed to carry out surveys either along or across the longitudinal axis of the survey area. The ultrasonic transducers are installed along the ship's axis, either in the keel or in a special support bar alongside the vessel.

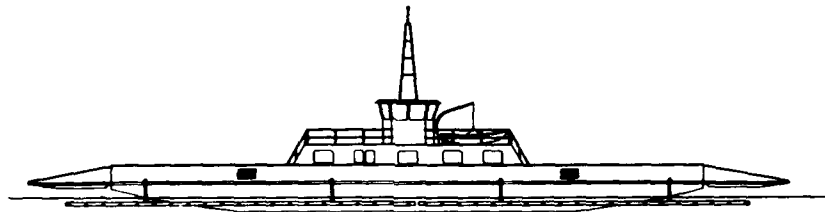


Figure 3a. Sweeping survey vessel with transducers installed along the side

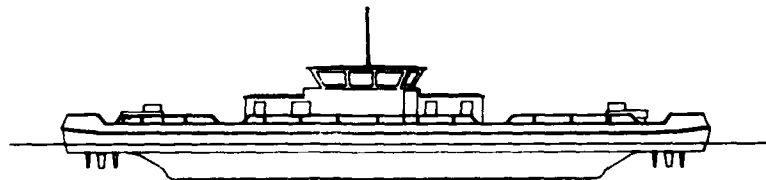


Figure 3b. Sweeping survey vessel with transducers installed in the keel

Survey vessels of this type are used in the river Rhine and in the Albert Canal of Belgium for detailed hydrographic surveying. Their sailing speed is relatively low, but their conversion into sweeping vessels was achieved at relatively low cost compared with the price of new vessels.

#### CONCEPT AND FUNCTIONS OF THE SURVEY SWEEP SYSTEM

In the following we want to look at the various components of a Total Survey Sweep System beginning with a basic BOTTOM MAPPER ATLAS-BOMA 20 and going up to the most sophisticated configuration.

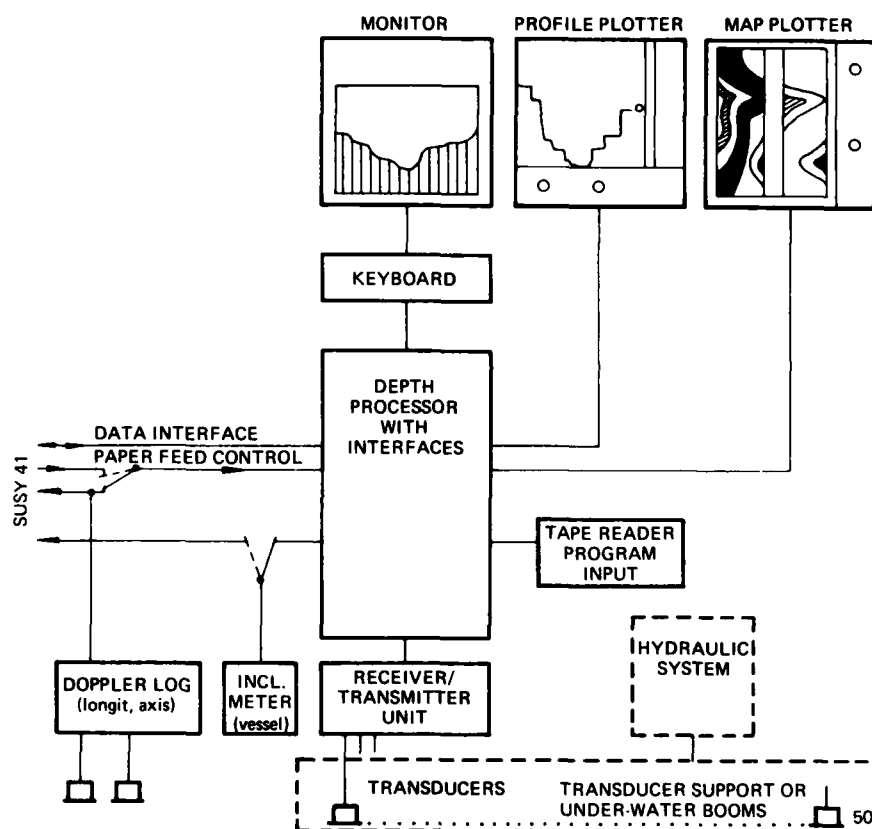


Figure 4. Bottom Mapping System ATLAS-BOMA 20, standard configuration

### The Echosounding Equipment (see fig. 4)

Leaving out the technical details of the systems, the equipment for safety surveillance or dredger guidance management consists of a number of ultrasonic transducers connected to the transmitter/receiver. A central computer controls the transmission and receives the depth information approx. 2 times per second over the whole sweeping width. Three outputs are provided by the system ( all of them display the data in the metric system):

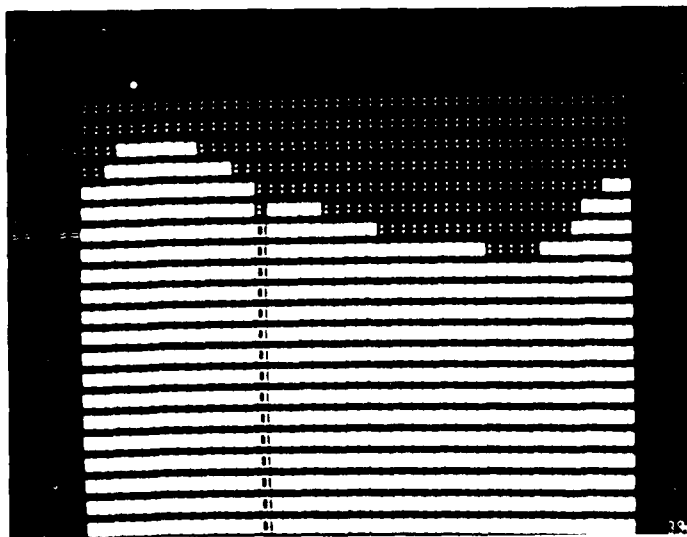


Figure 5. Bottom profile below the transducers displayed continuously on the CRT

Fig.5 shows the permanent CRT display, indicating the depth profile below the transducers for quick supervision of the sounding operation and for alerting the operator to any shoal depth situation.

The second output is the cross profile plot (fig. 6):

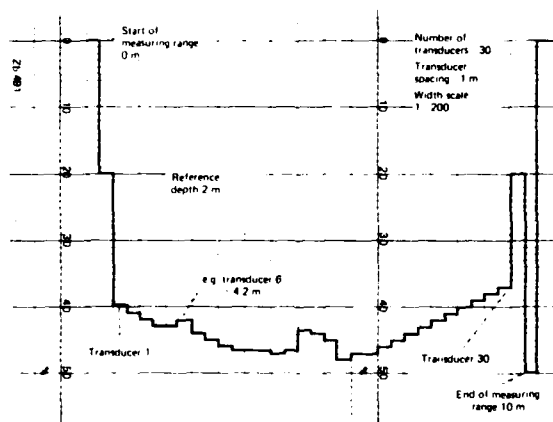


Figure 6. Cross profile plot

AD-A117 036

ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS F/G 8/5  
U.S. ARMY CORPS OF ENGINEERS SURVEYING REQUIREMENTS MEETING, 2---ETC(U)  
APR 82 E D HART, G C DOWNING

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It can be generated automatically in fixed time-increments or only if initialized by the operator. This output is basically a plot of the cross profile visible at the CRT at the specific time of event, but it can be plotted in different scales of both axes. This plot is very helpful for the later evaluation of the third type of output, the bottom map.

This is the important one - it presents a bird's eye-view map of the depths using a special dot matrix coding for the depth values.

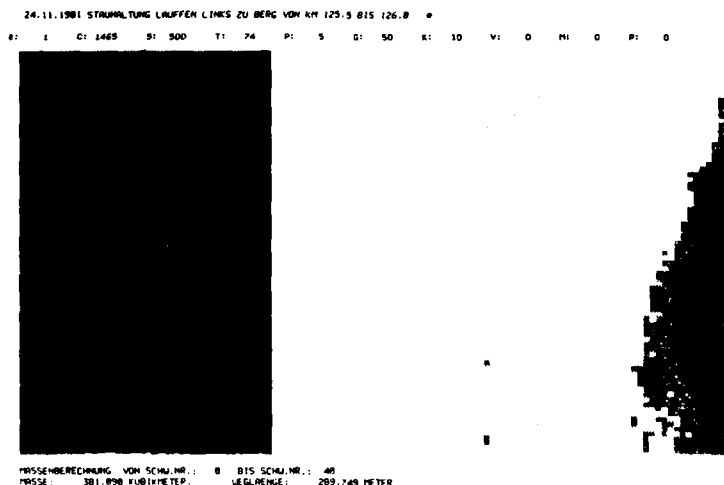


Figure 7. The bottom map  
Left: coarse depths Right: shoal depths

The presentation is two-fold: The left record shows all depths deeper - the right record all those shallower than a selectable reference depth, so that any shoal can be identified quickly at a glance. The depth resolution can be as fine as 0.1 foot although - for the sake of easy interpretation - most customers prefer a resolution of 0.3 foot on the shallow depth record (right side) and of 1.5 feet on the coarse depth record (left side).

If no other sensor input is available the map is driven with constant speed. The survey parameters are shown numerically at the beginning of a record.

#### Position Determination for Safety Surveillance

Adding a sonar doppler speed log ATLAS-DOLOG 11 to the system, the map can be driven true to the ship's speed over ground with an appropriate scale factor to achieve a true-to-scale record along and across.

Manual event marks can be generated to update the "zero distance" by using landmarks as a reference. The distance travelled since the last zero point is numerically plotted beneath the depth record.

For safety surveillance, this system configuration is frequently used in Germany. Most customers there employ Laser Range Finders ATLAS-LARA 10 to obtain an information about the parallel distance of the survey track with reference to the shore. Some vessels are equipped with a horizontal echosounder which indicates the distance to the shore to the helmsman of the vessel as an aid to keeping on track. However, this method works satisfactorily only in canals with defined and relatively steep slopes.

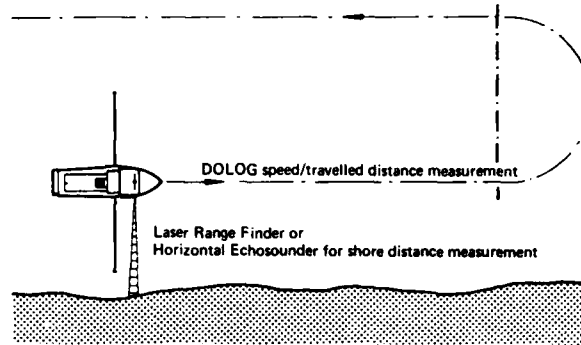


Figure 8. Course position determination without active reference stations

The above-described position determination principles, measuring the speed and obtaining the distance along track by using the Doppler Log, and additionally measuring the distance to the shore by Laser or horizontal echosounding, are adequate for safety surveillance and dredger guidance management. For this last mentioned task an additional software program can be implemented which calculates the volume of the bottom above the reference depth, formed from the single depth values appearing on the shoal depth record, multiplied by the horizontal transducer spacing and the associated distance increments. The result is numerically plotted at the end of a record.

With the above mentioned position determination methods the distance accuracy obtained from the Sonar Doppler Log ATLAS-DOLOG 11 is typically  $\pm 5$  feet  $\pm 0,5\%$  of the distance travelled. Under favourable acoustical conditions the figures can be much better. The accuracy of the distance to shore using either method, Laser or horizontal echosounder, can be assumed to be in the order of 5 - 10 feet depending on the cycle of measurements.

#### Position Determination for Hydrographic Surveying

As mentioned earlier, the positional accuracy in rivers and canals for hydrographic purposes should be better than 10 feet. For detailed analysis of morphological problems the requirement may even be less than 3 feet.

In wide survey areas or in curves of rivers and canals, a high accuracy figure may also be required for safety



surveillance because of the necessity of avoiding gaps between or too much overlapping of adjacent survey tracks. The same requirement also needs an efficient and accurate means to assist the helmsman in guiding the survey vessel on the desired track line.

Accurate position determination and verification of the depth values requires the storage of the data on a medium which is usable for automatic processing. The performance of all these tasks in the same processor that controls the depth sounding may be possible, but various considerations like system redundancy and modularity led us to design these functions into a separate subsystem - the automated Survey Navigation and Processing System ATLAS-SUSY 41 (fig. 9).

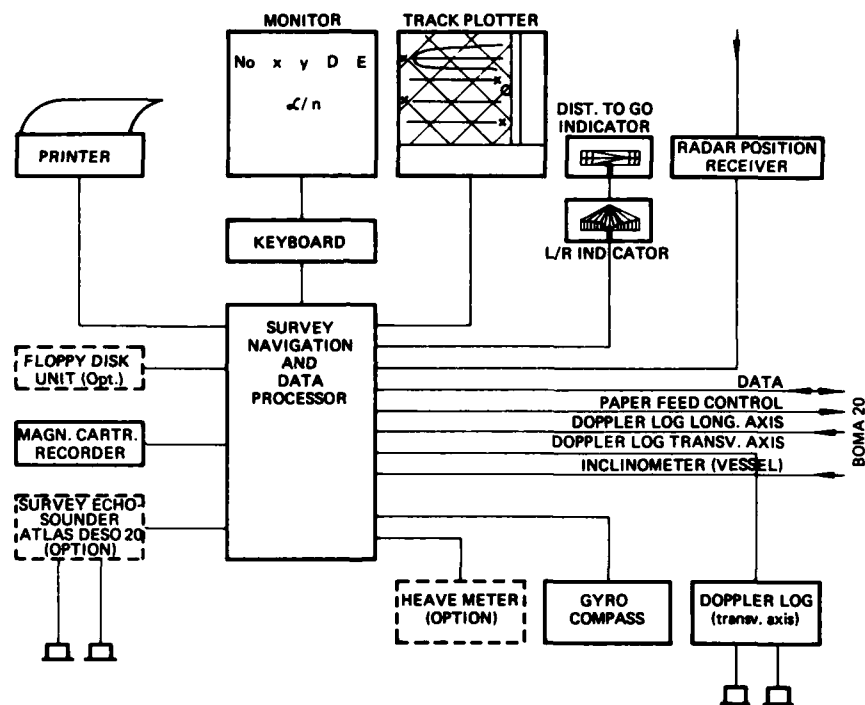


Figure 9a. Survey navigation and processing system ATLAS-SUSY 41; special configuration for sweeping and dead reckoning position

This sub-system provides of course all the standard functions known from automated survey systems and which will not be detailed here, but two major areas of performance are specific for the SUSY 41:

1. High accurate dead reckoning position determination using a 2-axis sonar doppler speed log and a gyro, in addition to the standard range/range positioning.
2. Comprehensive post-processing and graphic data output functions to provide cross section plots and numeric depth data plots from the depth data supplied from the sweeping system.

#### Dead Reckoning Position Determination

using a 2-axis sonar doppler speed log ATLAS-DOLOG 12 and a gyro compass Plath Navigat III is a special technique of KRUPP ATLAS-ELEKTRONIK BREMEN. The positional accuracy which can be achieved with this system alone is very much dependent on the bottom and on the acoustic conditions in the survey area; a typical value is  $\pm 5 \text{ ft} \pm 0,4 \%$  of the distance travelled in the longitudinal and transverse axes. However, this positioning information is only required within short distances, namely in those areas where the range/range position information of a radar position determination system like Tellurometer MRD-1, Mini-Ranger or Trisponder is disturbed. However, the dead reckoning position determination can also be operated without a radar positioning system; then, a position updating in appropriate distance or time intervals is necessary. For this application we integrate a Laser Range Finder ATLAS-LARA 10 into the system which allows the measurement of the ranges to triple mirror reflectors on shore with an accuracy of one or two feet. When this position updating is carried out at intervals of between 1,000 and 1,500 feet, the procedure provides an accuracy of about 10 feet between the updating points - an acceptable figure in areas with poor radar positioning conditions.

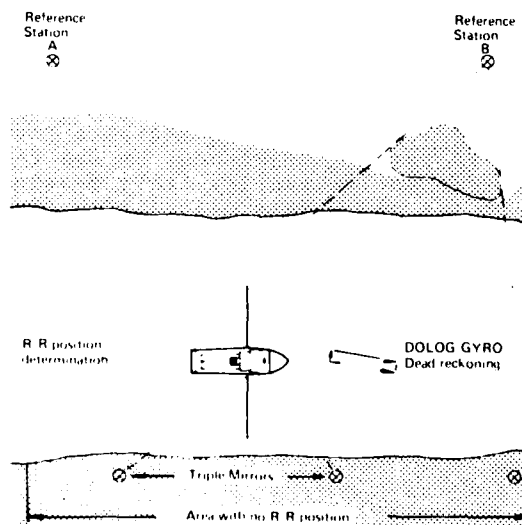


Figure 9b. Range/range or dead reckoning position determination with ATLAS-SUSY 41

If used in combination with the radar positioning, the dead reckoning position calculation can be performed in parallel to the range/range position calculation process and updated by each position which is deemed "good" according to preset variance limits. If the range/range position is "no good" or upon operator request, the dead reckoned position will not be updated anymore until the operator turns the system back to range/range. In this phase of operation the dead reckoned position from the DOLG 12 and gyro will be the primary information for navigation and track plotting, but all residual data from the range/range system will still be recorded on tape for eventual later evaluation.

From the foregoing you may draw the conclusion that it needs rather sophisticated position determination systems to carry out high-accuracy surveys in inland waters - yes, indeed this is true: If the survey operation needs to be safe in terms of covering the area completely and if the survey operation needs to be efficient in terms of covering the area quickly, then it needs a sweeping survey system with highly specialized position determination equipment.

#### Post-Processing of Depth Data

The depth data from the BOMA 20, i.e. 50 depth values approx. 2 times/second, are stored on magnetic tape cartridges together with the position data and with correction data such as vessel movement (roll, heave) or water level variations.

Before the survey operation is carried out, preplots, coordinate entries of reference stations and so on are performed like with any automated hydrographic survey system. However, special software programs are necessary to evaluate and output the large volume of depth information in a format ready for the user of the information:

- The numeric area depth point plot presents the depth values of each individual transducer or the average or minimum of a group of transducers (this depends on the scale of the map). When calculating the position for the depth information, the actual gyro course and the position offset of the antenna position are also taken into the formula (see fig. 10).

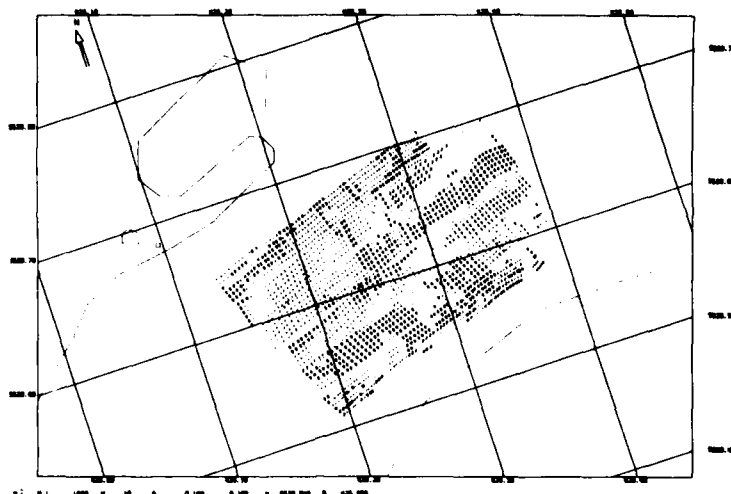


Figure 10. Numeric area depth point plot

- The depth line symbol plot actually provides the detailed information for drawing depth contours in that it shows a symbol for the depth line which is the next shallowest to the actual depth of the transducer or to the average or minimum depth of a selected group of transducers.

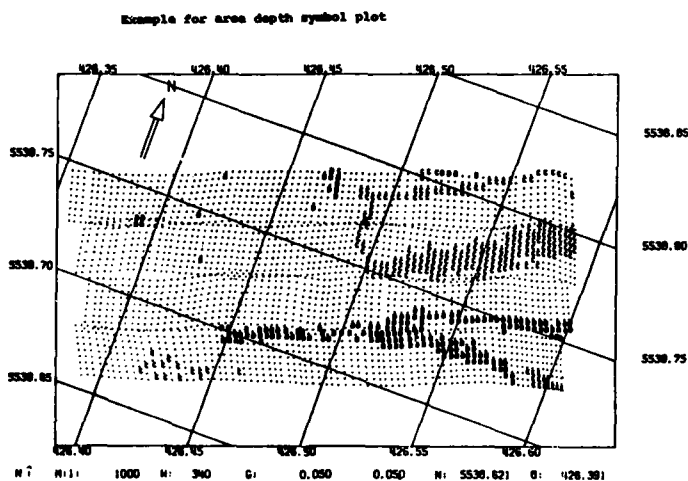


Figure 11. Depth line symbol plot

- The area-to-profile conversion program provides the means to "cut" a cross section out of the areal depth data field. The direction of the cross section can be at any angle with respect to the direction of the actual track of the survey vessel. The program allows various data files to be searched for depth data fulfilling the criterion, so that a complete cross section can be reconstructed out of the depth data fields of various adjacent survey tracks.
- The volume calculation program provides positive and negative volume calculations within an area defined by reference track line and sweep width and with reference to a constant depth or a reference depth profile. The program eliminates overlapping areas if the sweep width definitions are specified properly.
- The graphic cross section plot is standard in most survey systems. The speciality of this plot is its horizontal accuracy of the depth information. These were, as you may recall, derived from areal depth data in a conversion program, and now only those depth values are taken which are found within a specified parallel distance from the profile line.

It is possible with the system to store shore profile data on tape before the graphic cross section plot is activated. In this case the post plot can combine both hydrographic and geodetic profile data to provide the complete information in a ready-to-use format.

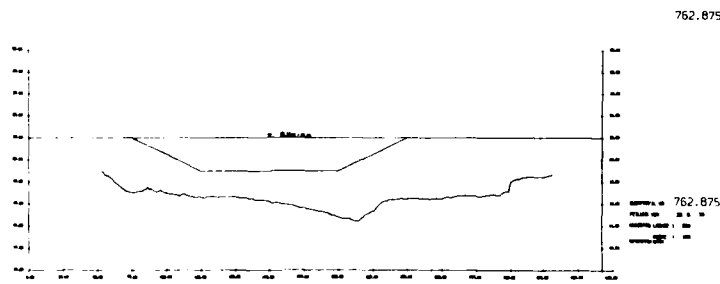


Figure 12. Graphic cross-section plot

This depth information can also be plotted in a numerical format in a plan view.

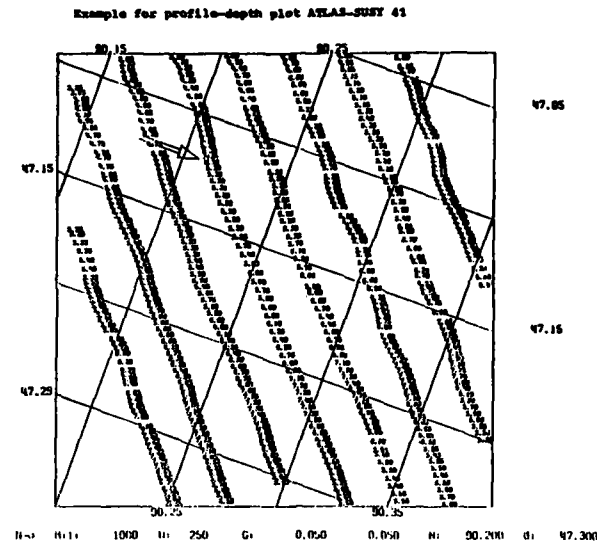


Figure 13. Numeric cross-section plot

Both the graphic and numeric cross-section plot can be performed using data from the standard survey echosounder ATLAS-DESO 20 instead of the ATLAS-BOMA 20 data.

The following figure shows a block diagram of the main programs and inputs/outputs of the ATLAS-SUSY 41 system.

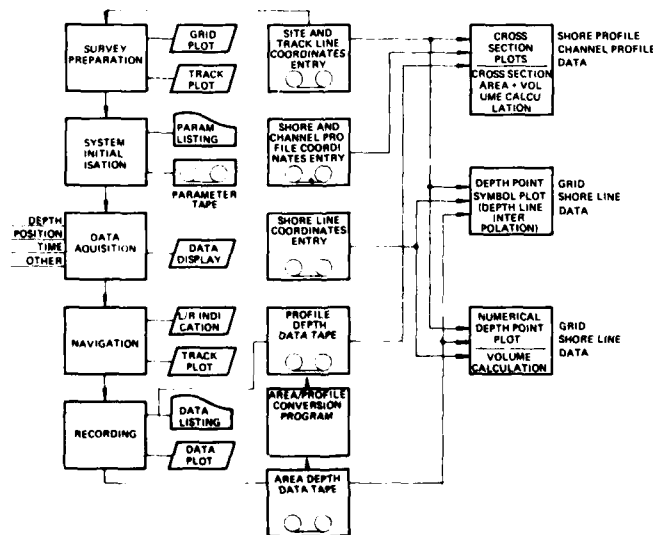


Figure 14. ATLAS-SUSY 41 system; block diagram of programs and input/output media

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SESSION III: DREDGING SURVEYS



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WRSC  
Cochairman



Roger Pruhs  
Norfolk District  
Cochairman

*Speakers*



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## SURVEYING REQUIREMENTS MEETING

Jacksonville, Florida

### INTRODUCTION

by

Mr. W. R. Murden, Water Resources Support Center

I am favorably impressed with the variety and scope of subjects scheduled for discussion during the conference.

1. Conference organizers and participants deserve a lot of credit; planning and arranging a meeting of this sort takes time and effort.

2. I began my career in surveying and recall those years with pleasure and a sense of satisfaction.

Surveying is an essential component of most engineering and construction projects.

1. This fact certainly applies to the Corps program and projects.

2. Whether it be hydroelectric projects, flood control projects, roads, real estate boundaries, location of hazards to navigation, locks, or dredging - surveying is a necessary and important element of the activity.

Navigation and Dredging are the missions of greatest interest to the dredging division.

1. In most activities, surveying is essential but not a continuing element of the function.

2. In contrast - surveying is a continuing and companion activity with dredging projects and programs.

3. Safety of navigation, as related to maritime traffic, is determined from surveying data. Mariners depend on surveying information to navigate their ships through the depths and widths available in the channels.

4. Surveys are essential in the planning and management of all dredging activities.

5. In the hydrographic field, we dredgers are your major customers. So, there is a need to maintain a close and high level of contact and coordination between surveying and dredging personnel.

#### McFarland Status -

1. Fire in machinery room (propulsion).
2. Damage appears to be less than originally thought.
3. Still too early to make damage and cost assessment.
4. Board of investigation is at work.

5. McFarland fire has caused a change in plans. Must leave conference this afternoon. Regret the need to depart so soon.

Dredging Program - For past several years, the total annual program has been at the \$400 million level. The program follows guidance contained in PL 95-269 enacted by the congress in April 1978.

1. Law contains the familiar requirement that the majority of the dredging work load is to be performed by the dredging industry. This guidance, based on timely performance and economical performance, has been in effect in prior legislation since the 1920's.

2. PL 95-269 has a new provision - that the Corps will operate and maintain a technologically modern "Minimum Fleet" of dredges to respond to emergency and defense needs, both in the U. S. and overseas. So we will have a much smaller fleet, but it will include modern vessels.

3. Congress has authorized and funded three new Corps hopper dredges as a nucleus of the minimum fleet.

- a. Yaquina - was delivered to the Portland District last year. A small class hopper dredge built by Norfolk Shipbuilding Corp.
- b. Wheeler - river trials are under way in the New Orleans area. A large class hopper dredge built by Avondale Shipyards, Inc., in New Orleans.
- c. Essayons - scheduled for delivery in fall of 1982. A medium class hopper dredge being built at Bath Iron Works, Bath, Maine.

Industry Hopper Dredge Program was begun in FY77, and has 9 hopper dredges in operation.

1. Includes 1 large class, 5 medium class, and 3 small class hoppers.

2. A 10th industry hopper dredge, a large class vessel, will be operational in May-June of this year.

Corps hopper dredge operations have not and will not require the number and detailed surveys as required by industry hopper dredge operations.

1. Therefore, there is a need for us to adjust our thinking and planning for survey operations and activities.

2. Accurate and timely surveys are needed to determine the quantity of material to be excavated so that the contract plans and specifications reflect the scope of the work to be performed.

3. Frequent surveys are required during the course of the dredging operations to assure that the contractor's dredges are most efficiently utilized and the contract completed at the earliest possible date.

4. We also need to adjust our thinking and planning as to the need for soils analysis. With Corps hopper dredges, we need to know the nature of the material to be removed. This is an essential factor in the determination of pumping efficiencies. However, under Corps operations,

there is no potential for claims or contract adjustments if we encounter materials which were not known to be difficult to excavate. Under contract operations, it is critical/essential that the nature of the soils to be dredged be known at the time the advertisements for bids are distributed. From my experience, our Divisions and Districts are not giving this matter the attention it deserves.

Summary - Surveying is an essential element of most engineering and construction activities of the Corps, and is a continuing element in dredging management and operations.

Public conception of the importance and elements of both dredging and surveying programs is very limited.

The expertise and the motivation needed to do the dredging and surveying missions are available, in abundance, in the Corps. This is not our problem.

Our mutual problem is to concentrate some of our efforts toward improving our image and making everyone - in the Corps and the general public - aware of the importance of surveying and dredging. Let's work together towards this common goal.

It's been a pleasure to be with you today. I wish the schedule would permit me to remain and enjoy the interesting papers scheduled for the remainder of the conference.

**MANAGEMENT AND MONITORING  
OF  
DREDGE MATERIAL DISPOSAL SITES  
THROUGH  
PRECISION BATHYMETRIC SURVEY TECHNIQUES**

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**BIOGRAPHICAL SKETCH**

Dr. Robert Morton is currently Director of the Ocean Science & Technology Division of Science Applications, Inc. In this position, he is also chief scientist of the DAMOS program, a major study evaluating the environmental impacts of dredge material disposal in New England. Prior to joining SAI, Dr. Morton was employed as an oceanographer at the Naval Underwater Systems Center, Newport, RI. He received a BS degree in Geology from the University of Rhode Island in 1964, an MA from Duke University and a Doctorate in Marine Geology from George Washington University in 1972.

**ABSTRACT**

Dredge material disposal management procedures have recently been employed at the Central Long Island Sound Disposal Site to "cap" heavy metal enriched sediments from Stamford, CT with silt and sand from inner and outer New Haven Harbor. The objectives of these capping procedures were to isolate the enriched material from benthic fauna and the overlying water column.

Monitoring of the disposal operation was conducted as part of the Disposal Area Monitoring System (DAMOS) an important aspect of which was precision bathymetric mapping of dredge material distribution.

Surveys were conducted with a microcomputer controlled bathymetric survey system that provides unique capabilities and flexibility relative to survey control, data acquisition, and processing of results. This system allows continuous profiling over a grid with 25 m lane spacing, processes the data obtained and produces contour charts and volume difference computations for evaluation of dredge material distribution and stability over time.

Using this system, management of capping operations were successfully completed and to date, stable deposits of dredge material have been created that effectively isolate contaminated sediment from the marine environment.

**INTRODUCTION**

During the past seven years, the New England Division of the U.S. Army Corps of Engineers has conducted an extensive management and monitoring program related to dredge material

disposal throughout New England. This Disposal Area Monitoring System (DAMOS) is a multidisciplinary project covering all aspects of monitoring disposal of dredge material in the coastal marine environment. This paper will be concerned with only one aspect of that monitoring system related to measurement of post disposal dredge material stability through replicate precision bathymetric surveys.

Because a large amount of the sediment dredged in New England is contaminated with heavy metals, organohalogenes or PCB's, a major objective of the disposal management procedures has been to contain the material in small compact mounds that reduce the surface area of dredged material exposed to the marine environment and that can be covered or "capped" with cleaner sediment. These mounds have been created through application of point dumping procedures controlled either by taut-wire moored buoys or computerized Loran-C navigation systems. An important aspect of the DAMOS program has been oriented toward monitoring these dredged material mounds, both during disposal to evaluate the accuracy of placement, and over a long period of time, to determine whether or not the material is stable and contained within the site.

The procedures used to monitor this stability are based on hardware systems and software programs designed to produce extremely precise replicate surveys so that small changes in topography can be determined. These data are then be used to evaluate sediment accumulation during disposal, movement after deposition within the vicinity of the mound, or total loss of material from the disposal site.

The topographic changes are measured through repeated surveying of a grid established over the disposal site which has a lane spacing of 25 meters. In order to provide adequate precision for the replicate surveys over that grid, the data acquisition system used for this project had to meet several design criteria including:

- an accurate positioning system capable of providing precision range measurements to locate the ship within 2 m at ranges up to 40 km
- a flexible survey fathometer system capable of measurements between 10 m and 100 m depth ranges with a capacity for subbottom profiling or plume tracking when required
- a sophisticated helmsman's aid system capable of controlling a relatively large (65-100 ft.) research vessel within  $\pm 5$  m of the designated transect lanes
- a rapid and flexible data recording system that can acquire and record all necessary depth and position information within the one second update rate of the positioning system
- a data processing system that can provide results in a short time, aboard the survey vessel, so that the information can be used to manage disposal operations or to select sampling and measurement locations for monitoring studies
- an overall system flexibility to apply the inherent navigational accuracy of the survey system to other aspects of the monitoring program, such as replicate biologic sampling, instrument and buoy deployment or retrieval, and control of the disposal operation when necessary.

This paper will describe the system that has been developed in response to the above criteria, outline the approach used during conduct and analysis of the surveys and present the results of an important disposal management and monitoring program conducted at the Central Long Island Sound Disposal Area.

#### INSTRUMENTATION

The basic principle behind the DAMOS survey system has always been a requirement for flexibility both in field operation and data analysis. None of the standard commercial survey systems were considered applicable since specific software was required to conduct measurements in the proposed manner and continuing alterations to both operational and analytical aspects of the project would require frequent program changes. This requirement for flexibility lead directly to development of a system designed around a microcomputer which could be interfaced with the necessary hardware and could be continually updated through software modifications.

The first system used on the DAMOS project was based on a Hewlett Packard 9825A calculator and was used for several years with a high degree of success. The advantages of this system were its reliability, which was outstanding, its speed in processing range and depth data, and its flexibility in terms of data analysis. After several years, however, as newer microcomputers became available, several disadvantages of the HP system became apparent. Most important of these were:

- Flexibility - the requirement for programming the 9825A in HPL made all software specific to the HP calculator, so that procedures and programs developed for that system could not be readily transferred to other computers.
- Video displays - The HP 9825 A did not have an easily developed capability for sophisticated graphic displays on a video monitor has added significantly to the accuracy and ease of ship control
- Interfacing - The HP system was not readily adapted to interfacing with peripherals that were not HP equipment.
- Cost - With the advent of newer microprocessor systems, not only the cost of the computer, but all peripherals and interfaces were drastically reduced.

Because of these disadvantages, a new approach to the survey system was developed using modern microprocessor hardware and software. Two systems were designed, one which uses an APPLE II computer as the CPU and a second which is based on a Zilog Z-80 microprocessor with PROMS. The second system was designed for application to more standard surveying operations and has a major emphasis on operator/machine interaction, but no access to the software. The system which is described in this paper maintains the operator interface capabilities but is also a complete disk based system which can be reprogrammed in the field if necessary.

A great deal of thought went into the selection of the Apple II as the basis of the system, most of which was oriented toward insuring reliability in an adverse environment with a low cost computer. Information from various sources had

expressed doubts about the use of disk recording media aboard ship, and the speed and memory size of the microcomputers were also questionable. However, several features of the APPLE II indicated it would be satisfactory for such a system. These features were:

- Cost - Reliability was not a problem during development and early use of the system because the low cost allowed two computers to be aboard at substantially less expense than a single 9825A.
- Interfacing - Standard interfaces to all peripherals and to modern instrumentation made system integration a relatively easy task with most handshaking occurring in software rather than hardware components.
- Graphics - The video graphic display capabilities of the modern microcomputer are extremely advanced and readily applicable to survey system requirements.
- Software - Development of software in various languages such as Basic, Fortran, Forth, Pascal, etc. makes transport of programs to other computers a relatively easy task.

During the design period of this system major developments in digital hardware were also underway which facilitated the interfacing of position and depth instrumentation to the system. As it was configured for use in the DAMOS project, the major inputs to the computer were: 1) a Del Norte Model 540 Trisponder was used with a standard RS 232 C interface card to provide real time position data, 2) an Edo Western Model 248 transceiver with four (4) frequencies (3.5, 7, 24) and 200 KHz) to provide the range of depth and subbottom capabilities needed 3) a Model 519 Digital recorder and a Model 261C Digitrak unit interfaced to the transceiver to provide depth information to the system.

The system described above has been used extensively on the DAMOS project and other programs for a period of more than two years with impressive results. Reliability of the system has been excellent if proper care and transport of the units are provided. It has sometimes been necessary to clean and reseal the interface cards in the computer, but the mini floppy disk system has had no problems with field operation. The flexibility and speed of the microcomputer have been outstanding and the system has been interfaced with a variety of long and short range positioning systems; used to acquire environmental data in addition to depth; and has even provided navigation control and reconstruction for submarine torpedo exercises.

In summary, the approach of using a microcomputer system for survey control is certainly feasible with existing off the shelf equipment and the flexibility of these systems to perform other tasks makes them truly cost effective. In practice, the computers used for surveying on the DAMOS program are in fact, more often used for data analysis, word processing, accounting and other activities.

#### PROCEDURES

The system described above has been applied as part of a disposal management and monitoring program associated with dredging of Stamford and New Haven Harbors on the

Connecticut coast. Because bulk sediment analyses indicated that dredged material originating from Stamford Harbor was contaminated with heavy metals, management procedures were initiated to "cap" the Stamford material with silt and sand from New Haven Harbor. The objectives of the capping procedures were to isolate the polluted material from the benthic fauna and the overlying water column; to evaluate the relative merits of sand and silt as capping materials in terms of coverage, stability, and effectiveness in isolating contaminants, and to estimate recolonization potential.

Monitoring of the disposal operation was conducted as part of the Disposal Area Monitoring System (DAMOS) and consisted of precision bathymetric mapping of dredged material distribution, visual observations of the disposal mound surface and margins, chemical comparisons of dredged and natural sediment and sampling of benthic populations for recolonization and bioaccumulation studies. This paper is concerned primarily with the results and implications of the bathymetric monitoring procedures. During the disposal and capping operations, replicate precision bathymetric surveys were performed during the disposal and capping operations to monitor the volume and distribution of exposed Stamford material at the disposal site. Following the completion of the capping operation, additional replicate surveys were made to monitor the long-term stability of the capping material.

Since a computer was used for data acquisition, all corrections for ships draft, sound velocity and tidal height were made after completion of the survey and all adjustments on the fathometer were set to zero. Earlier measurements of tidal height at the Central Long Island Sound Disposal Site have indicated close agreement with predicted tidal heights under ambient weather conditions. Since this relationship was previously established and because additional corrections were applied that reduce tidal errors in the survey data, predicted tidal correction values were used for all surveys in this study.

Prior to the disposal of dredge material at this site, a survey grid was established consisting of 25 transects, 600 m long oriented in the east-west direction and spaced 25 m apart. While conducting the survey, range data were input to the computer which provided steering information to assist the helmsman in maintaining the ship's position relative to the survey grid. Since precision data were required for this work, surveys were only made on calm days and the errors in steering the ship were less than 5 meters either side of a given transect. This navigational precision was necessary for comparing replicate surveys since slight errors in position can cause large errors in depth over sloping bottoms.

Data acquisition was controlled by the sampling rate of the Del Norte Trisponder unit which was nominally one range measurement per second. Depths were averaged over this one second interval and recorded on cassette tape with corresponding time and position information.

Analysis of bathymetric data was first accomplished through the generation of depth sections along the transect lanes. Since each transect was reproducible with a positional accuracy of better than 5 meters, these sections provide a



means of evaluating the precision of the survey technique as well as small scale changes in topography. All depths on these sections were corrected for sound velocity, draft and tidal height.

Figure 1 presents a section of a representative transect across the disposal mound at the Stamford-New Haven South site. Assuming no significant change (i.e. deposition or erosion) in the depth of the ambient bottom at some distance from the mound, the precision of the depth measurements between successive surveys can be evaluated by comparing the depths at the extremities of the transect. At this site, it is apparent that there are no significant depth differences between successive surveys beyond the disposal mound.

Following development of the vertical sections, the data were inserted into a grid pattern for further analysis. This grid pattern was established such that each grid block was centered on a transect lane, had a north-south length equal to the lane spacing (25 m) and an east-west length equal to one half the lane spacing (12.5 m). This convention was applied to all surveys even though it was possible to establish a finer grid pattern by sampling more frequently along the transect direction. The finer grid pattern would, however, introduce a bias into the data since the resolution between lanes cannot be improved.

All depth measurements falling within the area of each grid block were averaged and a mean depth was assigned to each grid location. The matrix of depths was then used to develop a contour chart of the entire survey area. Contour intervals of .25 meters were drawn on all charts of the Central Long Island Sound Disposal Site.

All depth measurements falling within the area of each grid block were averaged and a mean depth was assigned to each grid location. The matrix of depths was then used to develop a contour chart of the entire survey area as shown in Figure 2. Contour intervals of .25 meters were drawn on all charts of the Central Long Island Sound Disposal Site.

Calculations of volume difference between successive surveys was then accomplished by comparison of the gridded data. The difference in depth ( $\Delta \bar{z}_i$ ) of each cell between successive surveys was determined by subtraction and then multiplied by the area of the cell to determine the net change in volume. These volume changes were then summed along transects and over the entire grid to determine the total volume change. A histogram and cumulative curve of the volume changes from each transect was then developed as shown in Figure 3.

The precision of the depth measurement had to be extremely high to achieve an accurate volume because small changes in depth were multiplied by the area of the survey. In order to increase this precision, additional corrections were made based on the assumption that no significant changes in depth occur on the natural bottom beyond the extremities of the disposal mound. This assumption was fully supported by the data presented in Figure 1. To make these corrections the average depth changes ( $\Delta \bar{z}_i$ ) for all grid locations in the first and last five lanes were determined. If these ( $\Delta \bar{z}_i$ ) were different from zero a correction was applied to the third and twenty-third lanes to set those differences to

zero. Correction factors for each transect were then determined by linear interpolation between adjacent lanes.

Small differences resulting from errors in tide, sound velocity or draft corrections were thus accounted for and the baselines of successive surveys were accurately aligned with each other. Corrections of this type, while always less than 10 cm, were important for increasing the resolution of the volume difference technique.

The errors in determining the topographic volume relative to a baseline were evaluated through a calculation of the standard error based on the standard deviation of the depth measurement. A conservative estimate of the precision in depth measurement by echo sounding which accounts for navigation, correction factors, topographic changes etc. is  $\pm 20$  cm.

Using this figure for the standard deviation of all depths within a grid cell, and assuming that the standard deviations of all cells were approximately equal, the error for the total survey can be expressed as:

$$E_v = \frac{A \sigma_z}{\sqrt{M(n-1)}}$$

where

A = area of survey =  
=  $600 \times 600 = 3.6 \times 10^5 \text{ m}^2$

M = number of cells  
=  $48 \times 25 = 1200$

n = number of measurements in each cell =  
6 (approximately)

$\sigma_z$  = Standard deviation of individual depth measurement  
= 0.2m

therefore,

$$E_v = 1200 \text{ m}^3$$

Since a depth difference ( $\Delta z_i$ ), between successive surveys, was determined for each grid cell, a contour program was applied to the difference data and a contour difference plot was generated as shown in Figure 4.. This chart provided information on the distribution of changes in depth resulting from the accumulation or loss of material. A contour interval of .2 meters was used on these charts with consistent results due to the correction procedures described above.

These techniques were applied to the monitoring of disposal operations at the Central Long Island Sound site from January to June, 1979, and to post disposal conditions through the present time. The data obtained during this study represent a significant improvement over previous disposal monitoring efforts for several reasons, including:

- use of precision navigation control to maintain 25 m lane spacing
- the nearly flat bottom available to provide a baseline datum
- the application of computer software to complete data sets to provide better calibration between surveys

- the careful management of the disposal operation in order to create a discrete disposal mound which could be evaluated for small topographic changes.

Whether or not these conditions can be duplicated in other areas depends on the topography and the management procedures utilized during the disposal operation, however, this study provided a unique opportunity to accurately measure spoil volumes and to evaluate the importance of such parameters as compaction, stability and capping.

#### DISPOSAL MANAGEMENT

Although the bathymetric monitoring procedures were applied at both the STNH-North site where Stamford material was covered with sand from New Haven, and the STNH-South site where silt was used, this report will emphasize the results at the South site, in order to save space. Prior to disposal, a 600 m<sup>2</sup> grid with 25 m lane spacing was established and two baseline surveys were made. An estimate of the precision of the volume calculation technique was made by comparing the difference between the two surveys which was only marginally greater than the error expected from theoretical considerations. Furthermore, the contour difference chart generated from the two surveys indicated that the errors were small and randomly distributed since all contours were either  $\pm 0.2$ m or zero and showed no consistent pattern over the survey area.

Disposal of dredge material from Stamford Harbor at the southern site reached a total of 37,800 m<sup>3</sup> (based on scow load records) on April 22, 1979. A survey of the site was conducted on April 24, to determine the distribution of spoil material prior to capping (Figure 2). This survey indicated that the disposal operation was successful in developing a small, discrete mound approximately 100 m in diameter and 1.25 m thick. Close examination of the vertical depth sections (Figure 1) indicated that the topography of this mound was quite variable, and thicknesses of 2 meters relative to the initial bottom were present. It is important to note that contouring, by its nature, will smooth and decrease the topographic expression of the mound, and although overall volumes are accurate due to averaging of all depths measured, specific features smaller than the grid size cannot be accurately resolved. These features can, however, be assessed in the vertical profiles, but only within the accuracy of navigation between successive surveys.

Calculations of total Stamford sediment detected relative to the January baseline survey (Figure 3) resulted in a volume of 35,700 m<sup>3</sup> or approximately 90% of the estimated volume deposited. The contour difference chart (Figure 4) indicated that there was additional material present beyond the immediate mound, and that it was possible for significant amounts of dredged material to be undetected by acoustic measurements unless the more accurate contour difference alignment procedures were used.

After April 24, 1979, silt from New Haven Harbor was dumped on the Stamford sediment at the south site until June 15, 1979. On June 20, a survey was made of the southern site (Figure 5) to determine the success of the silt capping operation. The contour chart and the depth sections (Figure

1) indicated that a distinct mound had developed with a minimum water depth of 16 m and a thickness of up to 4 meters over the Stamford sediment. Because the silt material from New Haven was cohesive, the resulting mound did not display extensive spreading. Although the sections indicated that all Stamford material was capped, future operations with silt should be designed to spread the capping sediment and reduce the thickness to some extent. The volume of New Haven sediment dumped as capping material at the south site was estimated at 76000 m<sup>3</sup> from scow load measurements, of which 72000 m<sup>3</sup>, or 95%, was accounted for by volume calculations.

Similar results were obtained from surveys at the STNH-N site, however, the sand was dumped over a period of one week using a large hopper dredge. Surveys were made during this period which permitted modifications in the disposal point to spread the sand cap over all the Stamford material. Since the sand was less cohesive, it tended to flow during deposition thus creating a broader, flatter mound than that developed by silt at the southern site.

The results of these surveys indicate that the capping procedures employed during the Stamford-New Haven disposal operation were successful. The precision disposal of Stamford sediment resulted in two small compact mounds that were readily covered with New Haven material. There was little apparent difference in the ability of sand or silt to accomplish the desired capping. In the case of sand, the capping layer was not as thick, but the smooth, dense nature of the deposit should act as a tough, impervious blanket over the original dredged material. Silt deposits on the other hand, derive their capping ability from the cohesive nature of the sediment, developing a thicker deposit with rougher micro-topography.

Several recommendations for future capping operations can be made based on the data obtained from this study:

- The dredged material to be covered must be cohesive to reduce its spatial scatter. This would normally be the case since higher concentrations of contaminants are generally found in fine grained cohesive sediments. However, dredging procedures must be conducted in a manner to preserve this cohesiveness.
- Point dumping of the material to be covered should be done as accurately as possible, preferably with a taut wire moored buoy as a disposal marker.
- Disposal of the capping material should be accomplished as soon as possible, also using the buoy as a marker.
- After disposal of approximately 2/3 of the capping material at the disposal point, the remainder should be dumped in a circle with a radius equal to that of the initial spoil mound to insure capping of the flanks.
- Monitoring of the capping operation with bathymetric techniques should be done during disposal to allow for modifications in disposal operations required to insure coverage.

## DISPOSAL SITE MONITORING

Evaluation of long term changes in the shape and volume of the disposal mounds required an initial baseline for comparison similar to that used in the operational monitoring phase of the project. For post-disposal studies, the June 20 survey of the southern site (Figure 5) was used.

On 7 August 1979, a bathymetric survey of the south disposal site was conducted (Figure 6) that indicated there were no significant changes in the topography of the mound. Examination of the depth sections supported this conclusion, since in all cases the small scale topographic features were unchanged although the mound had settled or compressed slightly, increasing the water depth by approximately 20 cm. Calculation of the volume difference indicated the total volume change for the entire survey was a decrease of 900 m<sup>3</sup> which is well within the precision of the analysis.

The surveys taken in August 1979, therefore, supported the contention that the disposal sites were containment areas and that only minor modifications to topography caused by compaction generally occur after disposal. These results were expected since a similar mound from the 1974 dredging of New Haven Harbor has been stable for several years indicating the containment potential of the disposal site.

A second post disposal survey was conducted on November 7, 1979, to evaluate changes resulting from the addition of dredged material to the mound. However, the results of this survey showed a major change in the topography of the mound resulting from the loss of approximately 10,000 m<sup>3</sup> of material from the top of the mound (Figure 7). Depth sections across the center of the mound revealed a flat surface at 19 meters indicating that approximately 2 meters of sediment had been removed. Some of that material was present, particularly on the northeast margin of the mound, where slumping had occurred, however, the build-up of material in that area could not account for all the missing sediment. Although this loss did not expose any Stamford material, further investigations were initiated to determine the causes of sediment movements and to evaluate conditions at the other sites.

The flat topography of the sediment surface at a constant depth suggested that erosion by wave action was a likely explanation for the movement of material. The passage of Hurricane David through the area on September 6, 1979 provided a possible energy source to create the wave motion required. However, other disposal mounds in the area were unaffected by the storm, hence a further possibility is compaction caused by large pressure fluctuations occurring during the hurricane. Since no changes have been observed after this event and since vertical movement of large blocks of dredged material under the effect of swells has been observed by divers, the latter explanation is receiving more and more creditability.

## SUMMARY

The precision bathymetric survey procedures employed to monitor the Stamford-New Haven disposal operation have been

successful in managing the capping operation and in monitoring changes that have occurred after disposal. With proper control of the disposal operation, these procedures can readily be applied at other locations.

The effectiveness of capping contaminated dredged material with cleaner sediments has not yet been completely determined since the loss of silty clay material from the New Haven south site amounted to 10,000 m<sup>3</sup> or approximately 12% of the total capping material. However, since all of this material was lost from the upper surface of the mound no exposure of Stamford sediment occurred.

Observations of the sand capped mounds in the Central Long Island Sound Site have indicated successful capping since they have shown no measureable changes in volume or distribution, even though these deposits have more shallow minimum water depths than the southern site.

This survey procedure continues to be an effective tool for management and monitoring of disposal operations throughout New England and could be applied in other areas as well. The utilization of microcomputers to control the survey operation, acquire the data and analyze the results has proven to be an extremely cost effective approach to such a program.

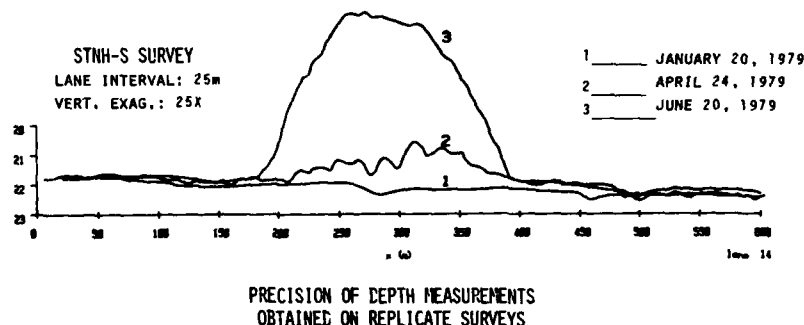


Figure 1

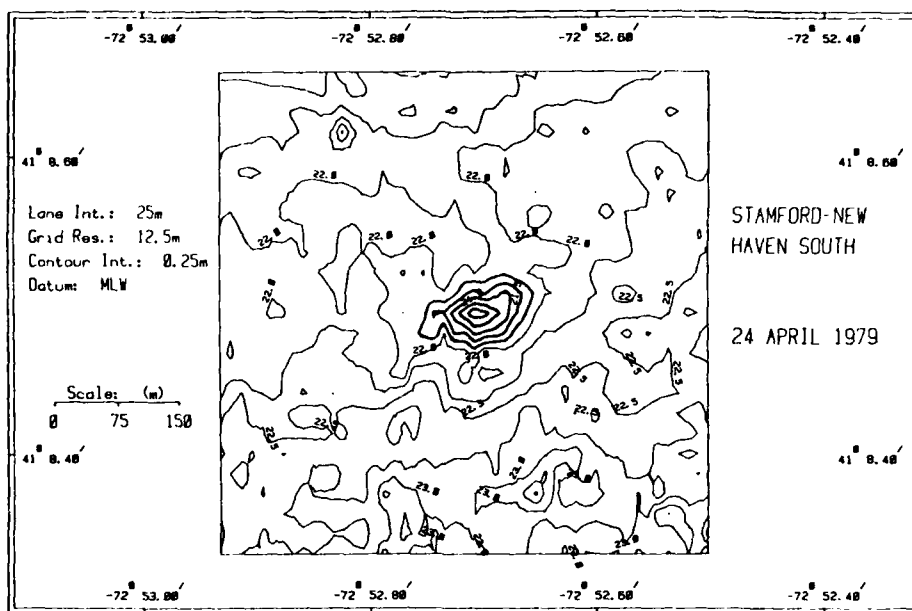


Figure 2

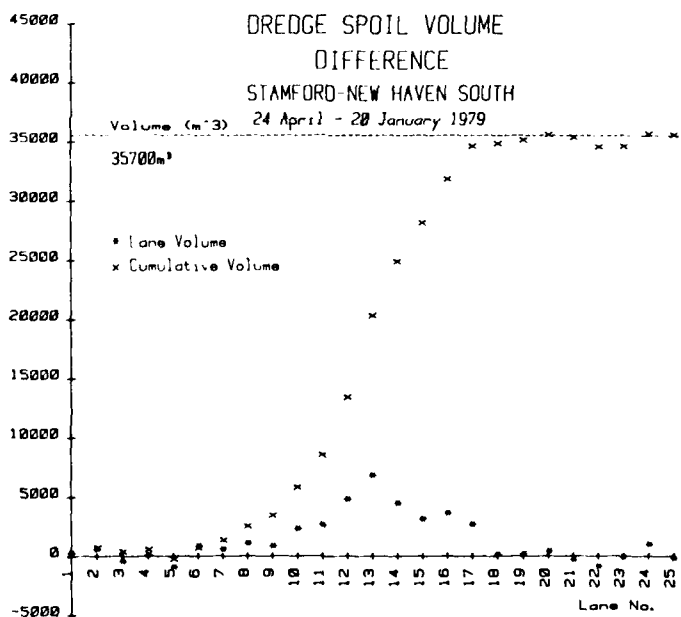


Figure 3

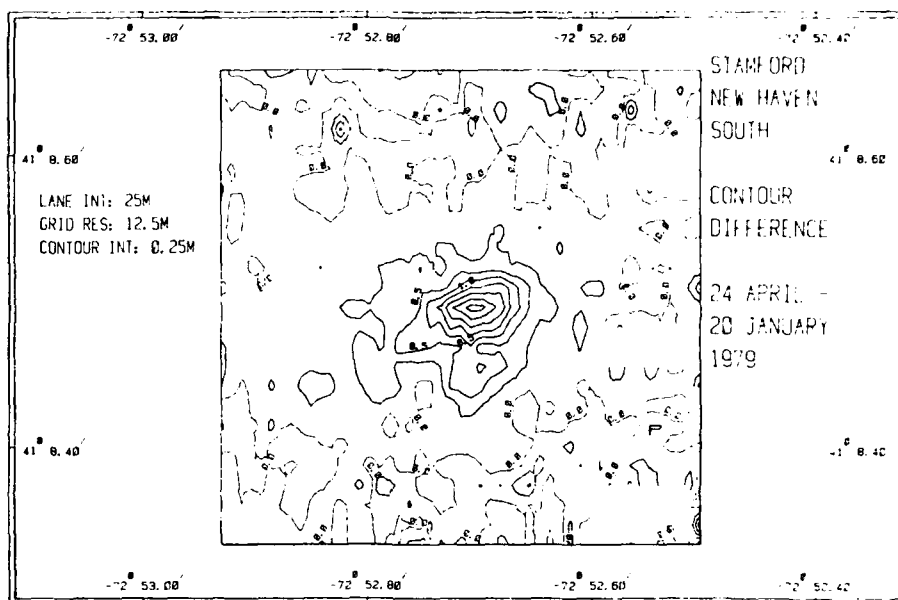


Figure 4

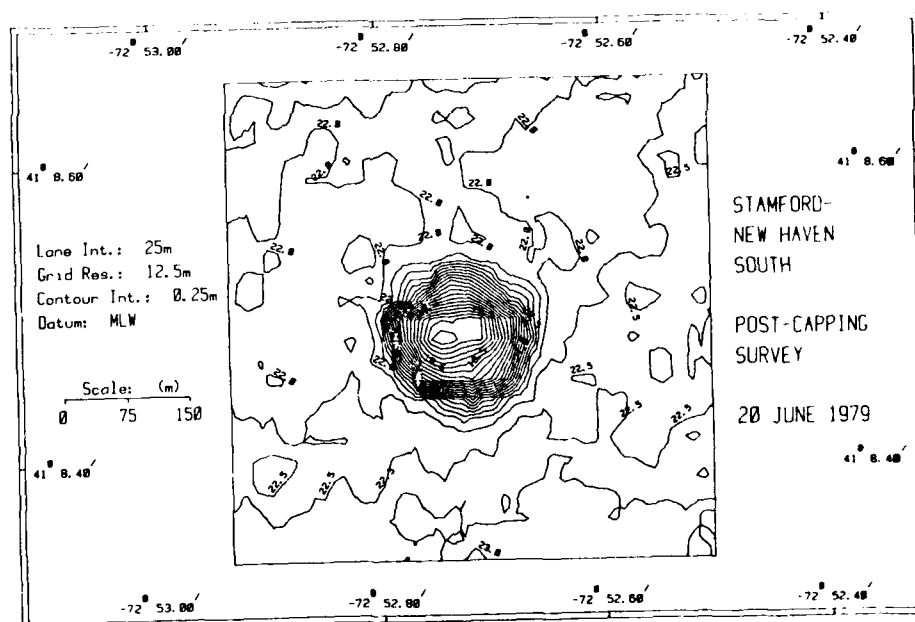


Figure 5



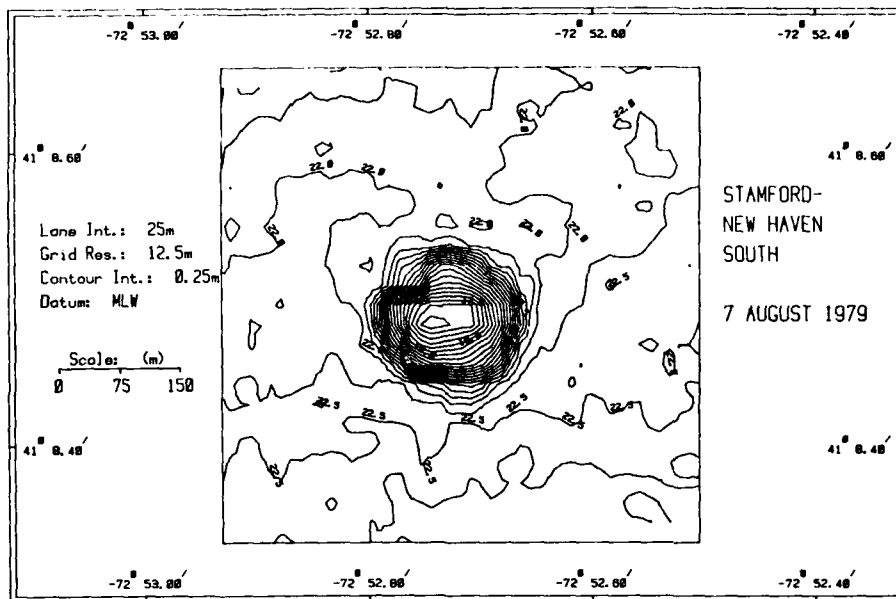


Figure 6

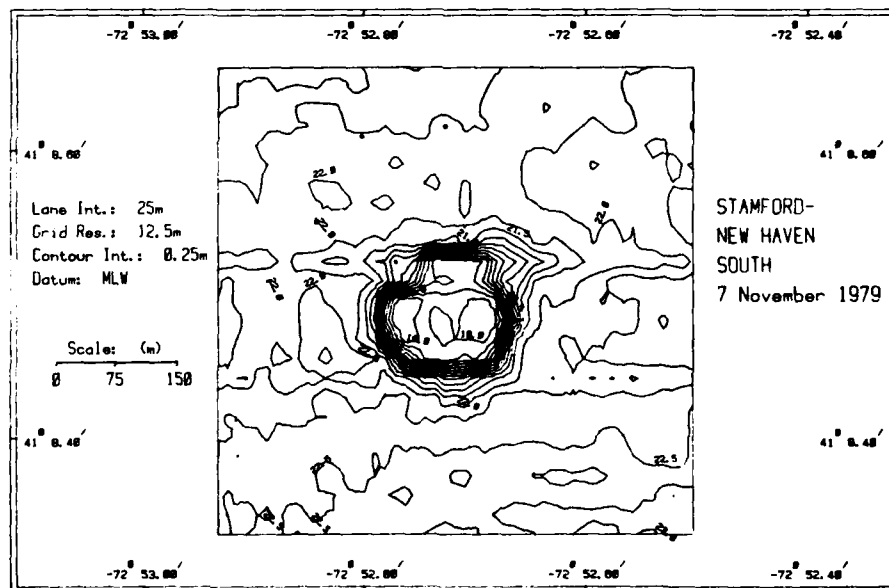


Figure 7

## IMPROVEMENTS TO HYDROGRAPHIC SURVEY SYSTEMS FOR DREDGING SURVEYS

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### BIOGRAPHICAL SKETCH

Stephen DeLoach is a Civil Engineering graduate of Virginia Polytechnic Institute and State University. In addition to fulfilling requirements for a degree in engineering he also completed studies in Surveying Specilization. Upon graduation in 1978 he took a position as a field engineer with the Tennessee Valley Authority in Scottsboro, Alabama. In 1980 he accepted a civil engineering position with the Survey Section, Norfolk District Corps of Engineers, where he presently works in close association with all District surveying activities. He is a member of ACSM.

### ABSTRACT

In 1978 it became apparent that the Norfolk District would become involved with private industry dredging of deep draft channels, associated with the channels deepening to Baltimore and Hampton Roads. This warranted improvements to our Hydrographic Surveys in order to increase accuracy and efficiency of survey operations. These improved techniques include: a better positioning system, more accurate dredging datum, better bottom definition, real time cross section plotting, and increased data storage and processing capabilities. Each of these subjects will be discussed as it relates to the hydrographic survey mission of the Norfolk District.

### INTRODUCTION

With the advent of contract dredging of deep draft channels the Norfolk District was forced to improve its hydrographic survey techniques. Primarily this was brought about by the deepening of the Baltimore Harbor and Channels, Virginia Portion, to 50 feet.

A study was made of our existing techniques by the Norfolk District, Survey Section. Several sources of error were found and improvements were recommended in a report entitled "Recommended Hydrographic Surveying Techniques and Dredging Controls for the Baltimore Harbor and Channels 50 Foot Project".

Specifically, the study made two recommendations: (1) A better positioning system; and (2) More accurate dredging datum. In addition to these we also determined it would be advantageous to: (3) Collect as much information as possible from the Depth Recorder and to: (4) Have the capability to plot real time cross sections, to scale. In order to handle the increased amount of data, we were forced to: (5) upgrade our data storage and processing capabilities, both onboard and in the office.

### Positioning

The positioning system used for all work done from our survey vessel ADAMS, was the Hastings Raydist range-range system. It is non-line of sight and uses phase comparison as a method of distance measurement. This system has served well and is still in use. A major drawback of this equipment is that it must be at a known coordinated position in order to initialize. Establishing such a position requires using spar buoys placed at the job site and conventional surveying techniques to locate them from shore. This is a time consuming procedure and requires considerable effort to maintain the buoys.

The positioning system is also subject to a number of inaccuracies, such as: positioning of the buoy; positioning of the boat over the buoy; having two ranges does not allow any redundancy for adjustment.

To alleviate the problem the District purchased a Tellurometer MRD-1. This system is line-of-sight, self initializing, self calibrating, multiranging, and multiuser. Tellurometer also claims an accuracy of one meter. Being line-of-sight limits your working range to about ten miles unless the shore stations are elevated. To accomplish this, Tellurometer supplied us with extensions to elevate the antenna but not the entire shore station. The self initializing, self calibrating features totally eliminate calibration buoys, therefore, saving a great deal of time and effort installing and maintaining the buoys.

By utilizing three ranges rather than two, the system provides a much higher degree of positional accuracy and reliability. Also, the system performs on-line least squares positional adjustments. This type of system was first used by the Corps in the Jacksonville District. Bill Bergen presented a paper on their systems at the hydrographic conference held in Wilmington in 1979. Much of our work in this area is based on their experiences.

After receiving the system we set up a test base at the Craney Island dredged material land fill, in Portsmouth, Virginia. The ranges were approximately 1 to 2 miles in length. The test was entirely static. At least 100 updates were logged by a line printer and a mean range and standard deviation was computed for each range. By subtracting the mean value from the known value a mean error was found. The mean error is the accuracy of the instrument whereas the standard deviation is the precision. The formulae used for standard deviation yields a one sigma percentage of only 68%. This is not a very high probability of occurrence and should be kept in mind when examining the results.

Figure 1 is a graph representing the statistical bell curves of the results obtained from the testing. The results shown for the Mini-Ranger only indicate 90% of the data received. Ten (10) percent of the data was rejected because it failed to be within 30 meters of the base distance. This was not done with the MRD-1. The solid curve indicates the MRD-1 information where the mean error ( $\bar{x}$ ) = 0.9 meters and the standard deviation ( $\sigma$ ) = 0.5 meters. The dashed line curve shows the Motorola Mini-Ranger information where the mean error ( $\bar{x}$ ) = 0.5 meters and the standard deviation ( $\sigma$ ) = 4.4 meters. Prior to discarding 10% of the Mini-Ranger data the mean error was 5.5 meters and the standard deviation was 25.2 meters.

Another item tested was a prototype space diversity antenna loaned to the District by Tellurometer. This antenna showed no significant change in the range data in a static mode. This was expected because space diversity is designed to eliminate reflections which did not occur over the static base line used for the test.

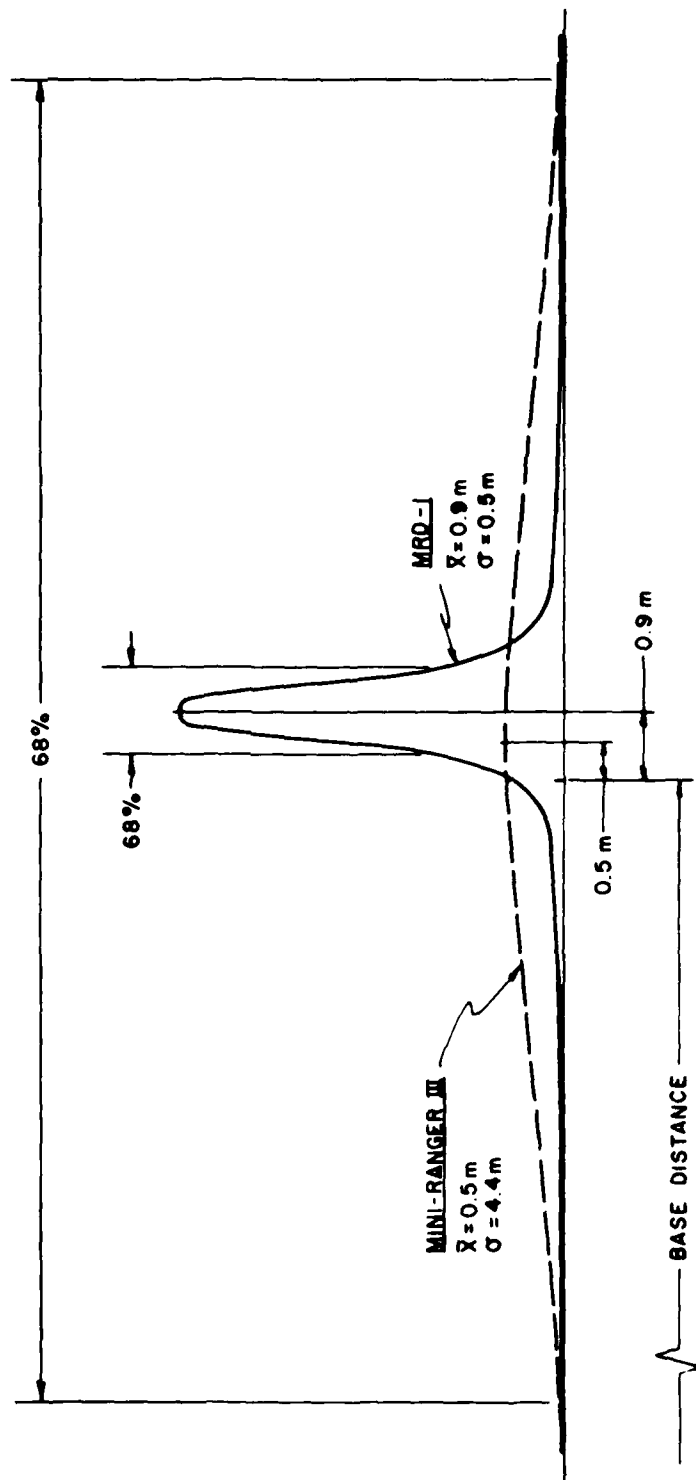


Figure 1

### Dredging Datum

The second item identified by the study was the need for a more accurate dredging datum. In past years surveys have been made utilizing a gauge on shore whereas the channels may be several miles from shore and up to 10 or 15 miles from the gauge. Because of the water level slope from the gauge to the survey site and the time delay in the travel of the tidal wave a significant error is introduced by an off site dredging datum and gauge readings. It was estimated that on the York Spit Channel this could add up to 5 million cubic yards of dredged material.

To resolve this problem, we incorporated a Wilmington District type of offshore gauge, the method of simultaneous comparisons, and mathematical zoning between gauges. The Wilmington type gauge was installed near the channel and operated for 3 months in conjunction with other National Ocean Survey gauges in the near vicinity. The method of simultaneous comparisons was used to establish a Mean Low Water datum on the gauge located on site. In order to remove the gauge and retain the MLW datum NOS is performing a mathematical zoning between the on site Wilmington type station and two other nearby on shore tide stations. This will enable the survey party to take readings from the gauge on shore and correct them for the actual tide on site.

### Increased Data Collection

Another problem associated with vertical accuracy is the proper definition of the bottom. Specifically, we collect a limited number of depths to define a survey line or cross-section. The present data collection system logs data at a specific distance interval along the intended survey line, i.e., 10, 25, or 50 feet, etc. From this data the average end areas and volumes are computed. However, if the bottom is very irregular, this may be an inaccurate representation. For example, if soundings are being logged every 25 feet and there is a depression in the bottom less than 25 feet wide, a sounding on either side may miss the feature totally. This coupled with the fact that before and after dredging sounding lines cannot be duplicated perfectly may result in errors in volumes and payment yardages.

To improve the results requires the collection of continuous depth readings instead of at a preselected interval. This creates another problem, data handling.

### Increased Data Storage/Processing Capabilities

To store and process the increased amount of data we replaced our on-board paper tape collection system with a DEC floppy disc unit. This unit, with minor software modifications, will allow every digitized sounding to be stored. At the end of a survey the disc will be turned in to the office for editing, final plotting, and yardage computations. Again, the increased volume of data will require modifications to our office computation system, a Wang 2200 MVP. In addition to minor software changes, the system was updated last year to allow time sharing on the Central Processing Unit. Thus, while the system is plotting one survey it can be editing another, calculating volumes on a third, and still be available for other personnel to utilize other various software packages.

### Real Time Cross Section Plotting

To aid in the definition of good and bad data we have also installed a DP-11 plotter on board the ADAMS. This will plot a cross section, to scale, in real time, thus allowing the system operator, or party chief, to detect any discrepancies between the survey presently being run with a previous survey. This is in addition to our track plotter which tracks the vessel plotting soundings as often as the selected scale will allow.

By comparing cross sections of the two surveys the operator will be able to detect: a horizontal shift due to positional or system error; bad soundings, which will be much more difficult to pick up on the analog depth recorder chart or teletype roll due to increased amount of data; or any vertical shifts which may be present.

### Cost

To purchase and install all the hardware discussed was quite expensive, however, when compared to the alternatives there was really no choice.

The positioning system, with some additional components, cost about \$150,000. Spar buoys for the 3 Baltimore Harbors Channels would cost from \$10,000 to \$20,000 each depending where they were installed. At 3 buoys per channel this would be at least \$100,000 to install spar buoys and these would not remain in place more than 2 or 3 months at best. Also, the MRD-1 gives redundant ranging which is extremely helpful in verifying positional accuracy in addition to eliminating calibration and initialization.

The gauging program for the three channels will cost about \$175,000. The only way around this cost is to not develop a more accurate datum. As mentioned before, this could make a difference between surveys of about 5 million cubic yards on York Spit Channel alone.

All the additional hardware such as the plotter and the floppy disc unit cost about \$45,000. The additional software was about \$35,000. It is impossible to put an associated alternative cost on the plotter and disc drive because these instruments allow the system operator to verify his data collection more accurately.

### CONCLUSION

Itemizing the overall system improvements:

MRD-1 positioning system allows for a higher degree of accuracy and reliability while not requiring calibration or initialization.

New techniques in off shore tidal zoning allow for a more accurate dredging datum.

Additional hardware and software gives a better definition of the bottom.

Real time cross section plotting enables the system operator to verify data more accurately in the field.

Therefore we have greatly improved our horizontal and vertical accuracy and improved the reliability of the results.

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MODIFIED SUB-BOTTOM PROFILER  
TO IDENTIFY AND MEASURE DREDGE AND BORROW MATERIAL

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BIOGRAPHICAL SKETCH

Ron Penton is Product Sales Manager at Ocean Research Equipment, Inc. with his primary functions being applications engineering and market development of new products. He graduated from the Control Data Educational Institute's course in Computer Maintenance in 1972 and then began work at the Woods Hole Oceanographic Institution's computer processing center. In 1975 he joined O.R.E., Inc. where he spent four years as a Field Service Engineer, installing and operating O.R.E.'s Seabed Survey and Acoustic Navigation systems on survey vessels world-wide. He is a member of the Marine Technology Society.

ABSTRACT

This paper describes recent advances in the art of acoustic sub-bottom profiling directed primarily at the dredging industry. O.R.E. now supplies a system which provides immediate information concerning sediment thickness and depth to bedrock or various clay or sand layers. The system is installed and operated by one man on a small or large boat with a minimum of training.

Based on years of experience with high-resolution profilers and pipeline location equipment, O.R.E. has designed this system with the dredging industry in mind. Simple variable controls give the operator flexibility while keeping total system operation quite straight forward.

Operating the system either before, during, or after dredging allows inspection of all sediment layers; displaying their depth and thickness. Example records will be shown along with discussion of theory of operation and benefits to users.

INTRODUCTION

The dredging and hydrographic industries have used acoustic systems for depth measurement for many years. Most of these systems are of the common "echo-sounder" or "fathometer" type which measure water depth by bouncing an acoustic pulse off the seafloor and measuring the time it takes to return to the survey boat. This time is converted to distance and displayed on a chart recorder, a digital display, or put directly onto magnetic tape for later chart processing. For simple depth surveys, generally operating in the 200 kHz range, these systems are efficient and effective tools.



When doing a pre-dredge survey, depth measurement alone is often not enough. To accurately estimate the most cost effective method to dredge a given area, information on the type of material to be dredged is necessary. Mud, sand, clay, or rock all demand different techniques, and a few random cores or drill holes will not provide an accurate picture of the entire dredge site. By utilizing the same theory of operation as used for the echo-sounder, but operating at lower frequencies and higher power, records are obtained accurately displaying all of the various layers of material to be dredged. Sediment thickness and depth is provided over the entire dredge area enabling the contractor to select the most efficient dredge method to employ and to accurately estimate the time required to complete the job.

#### SYSTEM HISTORY AND EVOLUTION

Utilizing acoustics for the purpose of measuring sediment and formation depth beneath the seafloor has been employed for decades by oceanographic institutions, oil and mining companies, engineering and construction companies, to name a few. Various methods allow investigation into the seafloor by providing anywhere from a few feet to five to ten miles of penetration. Many techniques and systems are available for this type of work but all operate under the same principles and face the same limitations.

The most important rule of any acoustic system is how the frequency affects resolution and penetration. Put simply: The higher the frequency, the greater the resolution, but lesser penetration. The lower the frequency, the greater the penetration, but resolution is sacrificed. (Note: While other lesser factors are involved, for the sake of brevity these will not be discussed in this paper.) This rule explains why a 200 kHz hydrographic system with resolution capabilities of an inch or less will rarely penetrate anything but a few inches of "soupy" mud, while an "oil-finder" system operating in the HZ region will penetrate miles of bedrock but provide resolution of only hundreds of feet.

It was found that a "happy medium" existed between these two extremes which could provide a wealth of useful information for a variety of applications.

In the late 1960's O.R.E. began producing acoustic systems which operated in the frequency range between 1 kHz - 12 kHz. It was found that by operating within this range it was possible to obtain records of sediment layers down to bedrock with penetration rates down to 300 feet and resolutions of .25 - 1 feet. The penetration capability varies depending on the type of material you are trying to "look" through. Typically silt and mud provide the deepest measurement while coarse sand or gravel does not allow the sound to penetrate as far. At these frequencies there will rarely be any penetration of bedrock at all.

The number of applications for a system with this capability is only limited by the users imagination. A few of the most common uses are:

1. Site investigation for offshore structures (drilling rigs or anchors).
2. Route selection for pipelines that have to be buried or that want to avoid rock areas.
3. Large scale mapping of areas searching for "borrow" material to be dredged up for construction purposes.
4. Route selection for power or telephone cables to be buried.
5. Mapping of a dredge site to chart sediment thickness and depth to bedrock.
6. Location and depth measurement of buried submarine pipelines.
7. Geological investigation of sediment deposits, slump areas, fault locations, etc.
8. Measurement of rate of fill of sediments behind dams, and in channels, harbors, rivers, etc.

As a result of supplying systems to users all over the world and operating many of the systems ourselves, O.R.E. has identified the need for a similar tool with features optimized for use by the dredging industry.

#### SYSTEM DESCRIPTION

The O.R.E. Dredge Sounder System was designed to the following specifications:

1. High resolution records in most bottom conditions.
2. Penetration rates of 10 to 50 feet in most areas.
3. Installation to be fast and simple by one man with no lifting equipment on any "vessel-of-opportunity".
4. Operation to be simple and straight forward -- so no special operators or long training courses are required.
5. Flexible enough to operate in a wide range of bottom types and operating areas or conditions.

By drawing upon many different O.R.E. products, we selected the components and features needed to fill the above requirements. The resulting system, named Dredge Sounder, is composed of the following three parts:

Transceiver. The Model 316 controls the frequency of operation, sends the transmit pulses to the transducers, receives the return "echos", processes the signal for optimum results, and sends the data to the recorder to be printed. The transceiver is in a splash-proof anodized aluminum case. All the controls and connections are on the front panel so the unit can be operated on a bench or standing on its back on the floor. Removing it from its case allows mounting directly into a standard 19" electronics rack. The Model 316 is roughly the size of a suitcase and weighs 45 pounds for ease in transportation.

Operating frequencies are 5 kHz and 16 kHz which are always operated and displayed simultaneously. The 5 kHz frequency provides the optimum penetration while the 16 kHz provides the optimum resolution. Controls allow the operator to vary the transmit power to compensate for various bottom materials and water depths. While the operator has the option of a few other adjustments for "fine-tuning", the transceiver can produce acceptable records without these. The circuitry

of the transceiver is on modular printed circuit cards for ease in rapid trouble-shooting and repair. On the average, an operator can be trained in system operation and general trouble-shooting in one day. (Refer to Fig. 1)

Recorder. A wide range of graphic recorders are available today which can interface with the Dredge Sounder System. All that is necessary is a single channel graphic recorder. The Model 316 Transceiver handles the task of operating at two frequencies and sends this to the recorder. Although any model recorder may be used, we recommend and supply an EPC Model 1600 Recorder for some of the following reasons:

1. Great flexibility and range of sweep speeds allows high repetition rate for optimum resolution.
2. Relatively small size makes for simpler handling (can be bench or 19" rack mounted).
3. Interfaces easily to navigation systems.
4. Modular printed circuit cards allow for rapid trouble-shooting and repair if necessary.

One of the features of the 1600 is that any portion of the water column may be removed from the record and the actual bottom profile may be expanded to provide maximum possible resolution. (Refer to Fig. 2)

Transducer Array. The transducer array and mounting hardware is of a field proven design which O.R.E. uses for many other profiling and navigation systems. Operational design parameters are as follows:

1. Simple and rapid installation by one man using no lifting equipment, no welding equipment, and no hull modifications.
2. Adaptable for use on a wide range of boat sizes and shapes.
3. Adjustable enough to work in various work areas but rugged enough to withstand day-to-day handling.

The O.R.E. Model 132DM Over-the-Side Transducer Assembly is constructed of heavy walled aluminum which has been hard-coat anodized. Areas experiencing high stress are made of steel which is hot-dip galvanized. All areas of contact are isolated by PVC or Delrin bushings to eliminate corrosion. The entire assembly is gimballed to allow deployment and recovery in many directions. Installation can be accomplished by bolting the unit to the deck or more commonly, bolting the unit to a length of lumber then securing the lumber to the deck. Average installation time is 1-2 hours.

The actual transducers at the end of the staff are enclosed in an A.B.S. shell to reduce flow noise and to avoid damage from impact with floating objects. Two 5 kHz transducers and one 16 kHz transducer are optimized for resolution and beam pattern. When out of the water in the "recovered" position, the entire array may be slid "in board" so the survey boat can come along side a dock. (Refer to Fig. 3)

Operation. The Dredge Sounder is a modified sub-bottom profiler. A detailed description on the theory of operation is available in many reference texts on the subject. (Refer to Bibliography)

From the viewpoint of the working dredging company, the entire system can be installed and collecting high quality data the same day. In the case of a pre-dredge survey, an accurate map can be created from the Dredge Sounder data showing all sediment depths and thicknesses in the proposed dredge area.

In the search for "borrow" material, large areas can be rapidly surveyed, available amounts of material displayed, and the material location pinpointed.

All data is produced in real-time (immediately), but it can also be stored on magnetic tape for later work or for creating a data library of areas surveyed. All data can be rapidly interpreted by survey personnel for immediate use by the dredging company in operation at the time.

Data Examples. Figure 4 was made during the dredging of the harbor of LaRoche, France by the Atlantique Dragage/Sodranord Company, The Netherlands. It clearly defines the various layers of clay, sand, and silt encountered or yet to be encountered during the dredging operation. Note at the edge of the records the slope down from the old seafloor into the recently dredged channel.

Figure 5 was made in the Maricaibo Ship channel in Maricaibo, Venezuela. Of particular interest are the two areas of very light sediment material. This is actually suspended sediment referred to by many as "fluff". In this case a standard fathometer shows only the initial bottom with no distinction between material types. While the material in the center actually had to be dredged, the "fluff" was merely "blown" out by the ships propeller wash.

#### CONCLUSIONS AND RECOMMENDATIONS

It has been proven that a tool such as the Dredge Sounder can accurately map sediment depths, thickness, and location. This can be done rapidly and efficiently by a survey company or dredging company personnel. It is obvious that both the estimation of a dredging job and the actual job can be greatly increased in speed and accuracy by utilizing this type of data.

It is our recommendation that any dredging job, regardless of size, scope, or location can be facilitated by the employment of such a system.

#### ACKNOWLEDGEMENTS

The author wishes to express his thanks to the staff of ORETECH, B.V. in The Netherlands for providing photos of equipment and sample data records taken during an actual dredging operation. I would also like to thank the various staff at O.R.E., Inc. who assisted in preparing the data, specifications, and typing of this paper.

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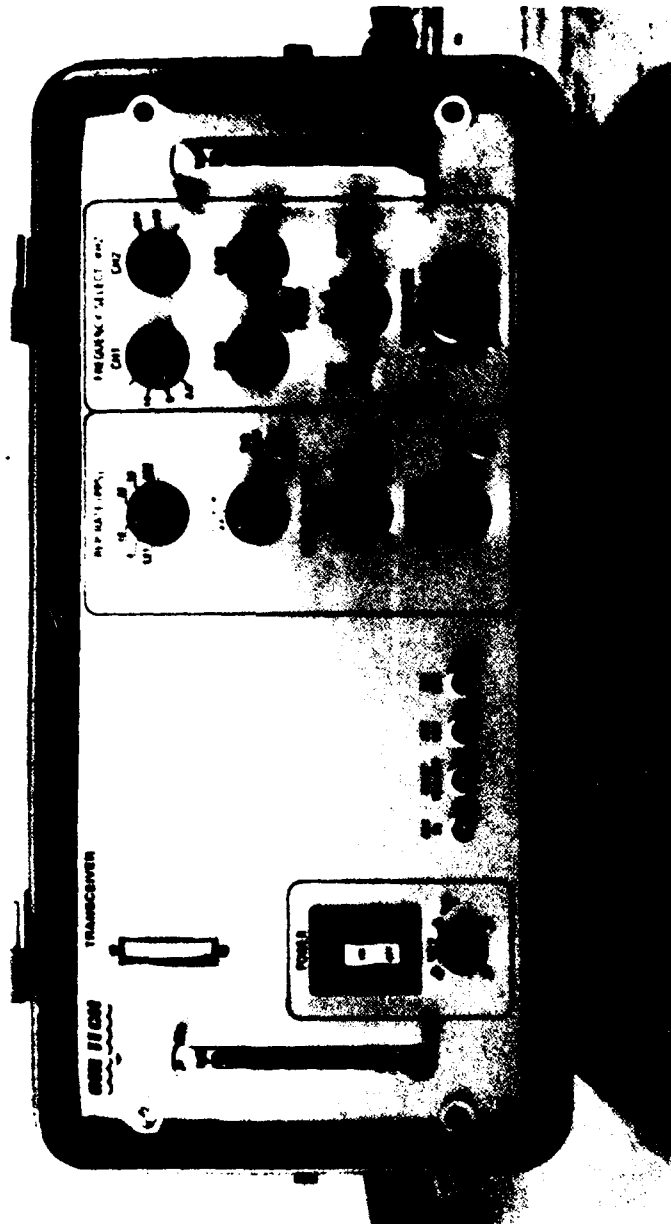


Figure 1. Front panel of Model 316 Transceiver

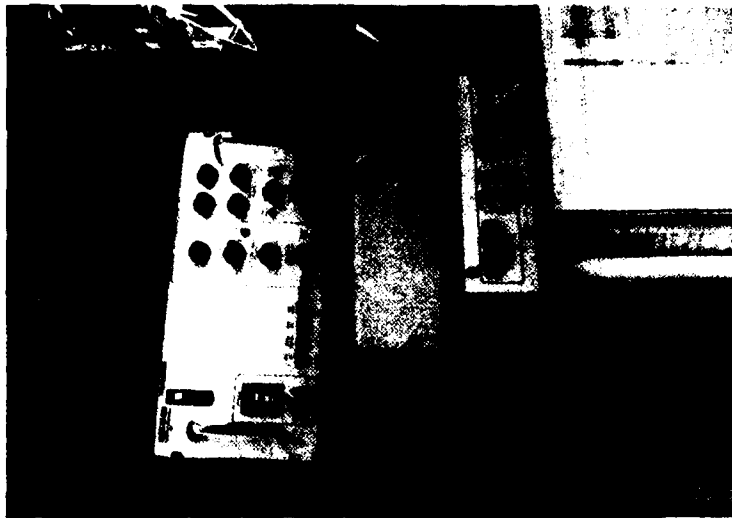


Figure 2. Model 316 Transceiver on end with  
Model 1600 Recorder on bench



Figure 3. Typical over-the-side transducer  
mounting arrangement

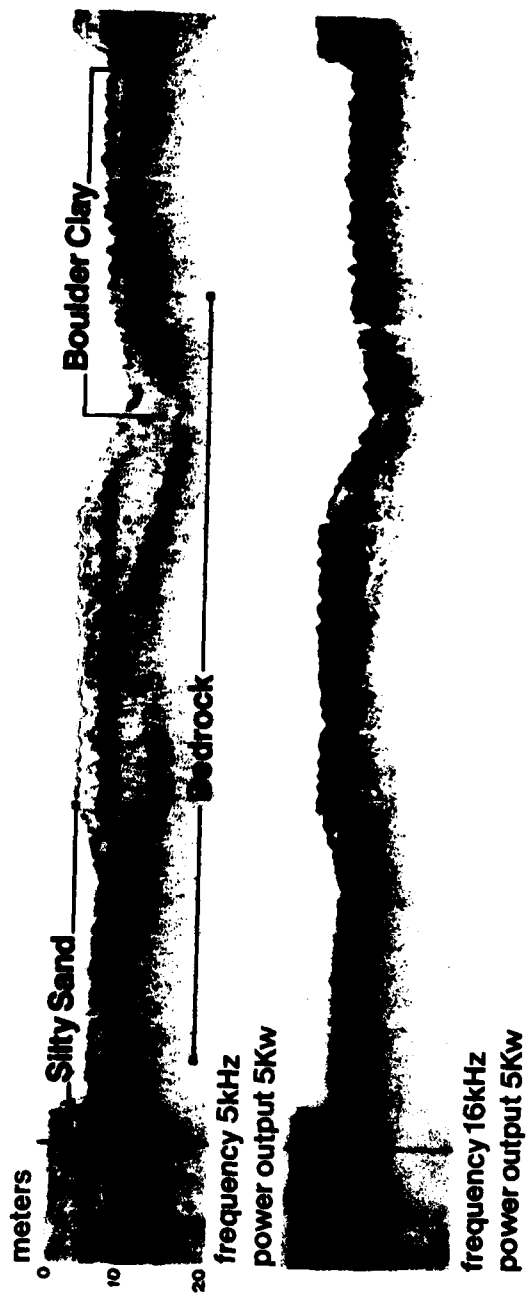


Figure 4. Dredge Sounder record of La Rochelle Harbor (France)



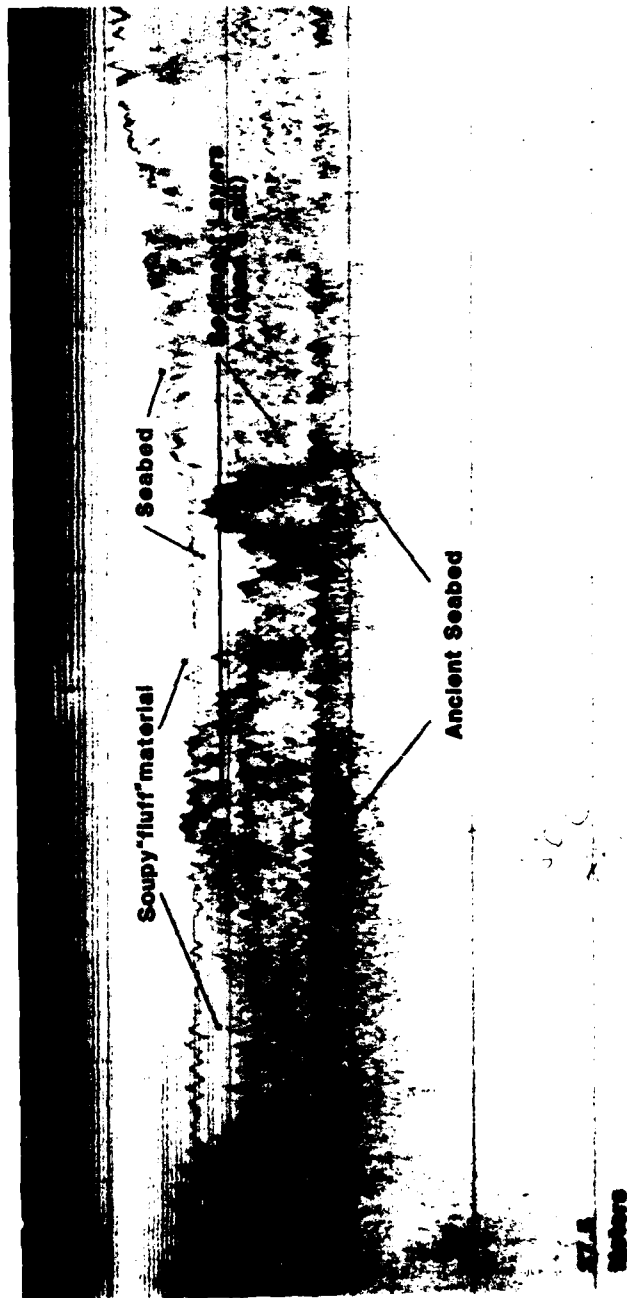


Figure 5. Dredge Sounder record of Maricao Ship Channel (Venezuela)

SESSION IV: TIDES



M. K. Miles  
OCE  
Chairman

*Speakers*



Lt. Cmdr. A. N. Bodnar  
NOAA



Eugene Batty  
Norfolk District



Bob Spies  
Philadelphia District



Paul O'Hargan  
Craven, Thompson &  
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## SESSION IV

### TIDES

#### Summary

This session was organized to highlight recent developments of equipment and techniques used in tidal work and to note the importance of tides and tidal datums in Corps surveying and mapping projects. Bob Spies of the Philadelphia District presented a paper on a new portable tide telemetry system for use in hydrographic surveying. Eugene Batty of the Norfolk District presented a paper on offshore tide gauging for dredging in the Chesapeake Bay. A method for determining mean high water line locations from tidal datums was presented by Paul O'Hargan of Craven Thompson. The National Tidal Convention of 1980 was presented by Lt. Cmdr. Nicholas Bodnar of the National Ocean Survey (NOS). M. K. Miles of the Office, Chief of Engineers, emphasized the need for the Corps to utilize NOS tidal datums for Corps surveying and mapping projects. Because of the interaction between the Corps navigation projects and the NOS charting functions, which both support navigation activities, the Corps datums should agree with NOS chart datums.

## NATIONAL TIDAL DATUM CONVENTION OF 1980

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### ABSTRACT

For the first time in history, the United States has been provided with one consistent tidal datum system. Four actions, known collectively as The National Tidal Datum Convention of 1980, have been required to modify the existing system in order to achieve this consistency. The actions are: (1) to compute the tidal datums of Mean High Water and Mean Low Water as the average of all the high and low waters, respectively; (2) to lower chart datum from Mean Low Water to Mean Lower Low Water along the Atlantic coast; (3) to change the name, "Gulf Coast Low Water Datum," to, "Mean Lower Low Water;" and (4) to update the National Tidal Datum Epoch from the 1941 through 1959 series, to the 1960 through 1978 series.

The Convention provides a tidal datum system independent of computations based on type of tide. Thus, of greater regional importance, a uniform and continuous tidal datum of Mean High Water (without vertical jumps due to change in computational method with type of tide) and a Mean High Water Line (without concomitant horizontal discontinuities) has been generated along the Gulf coast. Likewise, Mean Higher High Water has been created in areas of predominantly diurnal tides, thus providing a uniform and continuous Mean Higher High Water Line along the Gulf. Lowering chart datum from Mean Low Water to Mean Lower Low Water along the Atlantic coast and changing the name, "Gulf Coast Low Water Datum,"

to "Mean Lower Low Water," along the Gulf has placed chart datum at a common elevation for all tidal waters of the United States, U.S. Possessions and Territories, and U.N. Trust Territories under U.S. jurisdiction. Updating the National Tidal Datum Epoch adjusts all tidal datums for the effects of continuing long period sea level variations.

IMPLEMENTATION OF A  
NEW CONCEPT IN  
OFFSHORE TIDE GAGING

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BIOGRAPHICAL SKETCH

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ABSTRACT

The purpose of reading a tide stage when performing hydrographic surveying work is to adjust an echo sounding to a particular tidal datum, usually to mean low water. For most surveys within the Norfolk District, the tide stage can be directly applied to provide a true water depth referenced to mean low water. This paper considers a situation where real time soundings cannot be directly adjusted from off-site tide stage readings. A discussion is presented explaining the reason for this phenomenon, and an outline of implementing a solution is provided.

INTRODUCTION

The Norfolk District was contracted by the Baltimore District to provide hydrographic surveys within the Virginia portion of the Baltimore Harbor and Channels 50 Foot Project. The size of this project, in addition to the Corps advocacy of private industry to perform much of its dredging, resulted in an investigation aimed at evaluating existing surveying methods and identifying improvements. The Norfolk District was responsible for this investigation and the resulting report entitled "RECOMMENDED HYDROGRAPHIC SURVEYING TECHNIQUES AND DREDGING CONTROLS FOR THE BALTIMORE HARBOR AND CHANNELS 50 FOOT PROJECT." It identified existing survey deficiencies and recommended solutions. One of the deficiencies was the lack of a true on-site tidal datum. This influenced the development of a new concept in offshore tide gaging. The purpose of this paper is to introduce this new concept, that was developed by Mr. M. K. Miles and National Ocean Survey personnel, and report on its implementation.

VERTICAL CONTROL

The need for a more accurate on-site tidal datum came from the requirement to increase hydrographic surveying accuracy in the bay. Up until this time, dredging within the lower bay has been performed by Government owned hopper dredges. While credited yardage has always been made on in-place quantities, the actual payment for the plant was made on a rental basis. Consequently, the accuracy of the surveys was not critical to payment of work. At this time, it is anticipated that the payment for private industry dredging will be based solely on in-place quantities removed calculated from before and after dredging surveys. It is therefore imperative that the surveys be as accurate as possible with acceptable validity.

Normally, the Norfolk District strives for vertical accuracies of  $\pm 1$  foot in its hydrographic surveys. Some within the bay have vertical accuracies somewhat less due to a lack of a sufficient on-site tidal datum. To understand the need for such an offshore gaging program, it is important to realize the problems of improper application of a tide gage reading to an echo sounding. The water level slope and time differential between gage and project site must be considered. Hydrographic surveys within the Norfolk District are highly influenced by tidal effects. Surrounding rivers and waterways on the eastern shore of Virginia are project sites that comprise most of our work. Conventional tide gaging provides accurate direct adjustments to real time soundings in these areas. Operating on the bay, however, has certain tidal effects that require special attention.

There are three channels within the Virginia portion of the Baltimore Harbor and Channels 50 Foot Project. They include Cape Henry, Rappahannock Shoal and York Spit Channel. All three sites lack a true on-site tidal datum. According to the investigation, present vertical accuracies under worst conditions between before and after dredging surveys could have discrepancies that range from 1 to 2 feet depending on the channel and tide gage location. This could amount to a significant error in volume computations. Presently, our offshore gaging operation has dealt only with York Spit Channel. It is located approximately twelve miles from its tide staff in Cape Charles Harbor. The staff is referenced to a datum in the harbor and does not accurately account for on-site conditions. Implementing an offshore gaging operation to establish a true on-site tidal datum can produce vertical accuracies of  $\pm 1$  foot yielding a .2 foot error between surveys under worst conditions as determined by the investigation.

#### IMPLEMENTATION

The implementation employs five steps: a Wilmington type offshore tide gage; comparison of simultaneous observation; data reduction and mathematical zoning; tide telemetry; and on board hardware and software.

**OFFSHORE GAGE.** The method of recording tidal information offshore was modeled after a Wilmington type tide gage. The main support structure is a steel pipe which also serves as a stilling well for a portable automatic tide gage. This is advantageous because it provides a relatively inexpensive method of establishing an offshore tide gage structure that could be removed and used at another location. This method was chosen over a more permanent and expensive platform structure. Additional merits for the intended use of this gage are as follows: First, maintaining the gage for extended periods of time would not be required since a more convenient gage will be used during the surveying and dredging phase. Secondly, it would eliminate the threat of destruction from adverse weather. Finally, acceptable vertical datum accuracies can be obtained by comparison of simultaneous observations.

New Point Comfort Shoal, with a water depth of 20 feet, was the site chosen for the offshore structure. An 18-inch diameter steel pipe was driven into the bottom sediments approximately 20 feet. The Coast Guard cutter KINNEBEC and her crew were very helpful in this operation. The total length of pipe was 60 feet and it served as a stilling well for the tide gage. A platform was placed on top of the pipe to provide a work area. Once this was in place, the tide gages, tide staff, and light assembly were added.

Two Fisher - Porter tide gages were used to record the on-site tide information for three months. One served as the main gage and the other a backup. The installation and monitoring of this gage required setting a tide staff. The staff was set so that low water would not fall below zero. The staff water level was noted at time of installation and the automatic tide gages were calibrated to an arbitrary distance from the observed reading. For the next three months an observer checked the gage and recorded the staff and recorder readings. This information was then sent to National Ocean Survey (NOS) where the data was analyzed and monthly means were tabulated. Time and heights of high and low water were also tabulated for simultaneous comparisons.

COMPARISON OF SIMULTANEOUS OBSERVATION. To most accurately establish a tidal datum, data should be collected over a minimum of a 19-year Metonic cycle. Since this is often impractical, a comparison of simultaneous observations can be employed. This is a reduction process where a short series of tide observations are compared to simultaneous observations at a primary control tide station. The time required to run a short series observation is influenced by the desired tidal datum accuracy, distance from the control gage and topographic and hydrographic differences between the temporary and control gages.

Tide observations at New Point Comfort Shoal were compared to data from a NOS primary control tide gage at Hampton Roads and Kiptopeake. A NOS secondary tide gage at the Chesapeake Bay Bridge Tunnel was also used in the comparison, since it was relatively close to the channel and could reflect meteorological and astronomical effects on-site.

Figure 1 shows the Virginia portion of the Baltimore Channels and associated gaging. The gages shown at Windmill Point, Cape Charles Harbor and CBBT reflect the tide control stations used in the past for Rappahannock Shoal, York Spit and Cape Henry Channels respectively. Likewise, the gages shown at New Point Comfort Shoal, Kiptopeake, CBBT and Hampton Roads reflect those used in the comparison of simultaneous observations to establish a mathematical zoning for York Spit Channel.

DATA REDUCTION AND MATHEMATICAL ZONING. The reduction of tide data through simultaneous comparisons enables tide readings for off-site be converted to on-site conditions. A mathematical zoning model referenced to an off-site NOS tide gage will provide the conversion constants necessary to make on-site tide adjustments. Each zone contains a height ratio multiplier and a time difference constant. The height ratio multiplier accounts for the water level slope while the time constants adjust for the speed of the tidal wave between the off-site gage and project area.

Figure 2 shows a mathematical zoning in the Chesapeake Bay. It was recommended by NOS that zones above north latitude 37°05' be referenced to Kiptopeake NOS tide gage, while those south be referenced to a NOS tide gage on the Chesapeake Bay Bridge Tunnel.

See the following calculation for an application of this zoning.

EXAMPLE CALCULATION.

Assume that the Norfolk District survey vessel "ADAMS" is operating in Zone II-A as shown in Figure 2 and a tide gage is being read off-site at Kiptopeake Beach. The real time soundings in Zone II-A need to be adjusted to the on-site tidal datum.



Zone Conversion Constants: +15 minute time correction  
x0.81 height ratio

Time of Sounding	1045 hrs.
Tide occurs 15 min. later at Zone II-A	-15 mins.
Same stage of tide at off-site gage	1030 hrs.

Gage reading above tidal datum at 1030 hrs.	2.00'
Height ratio	x.81'
Off-site gage reading corrected for	1.62'
<u>Time and Height</u> for Zone II-A	

Therefore, if a sounding taken at 1045 hrs. measured 10 feet in Zone II-A, then the adjusted height below the on-site tidal datum would be 10-1.62 or 8.38 feet.

TIDE TELEMETRY. A telemetry device will be used to transmit the tide stage height from the off-site gage to the survey vessel. This will eliminate a manual gage reading and send data directly to an on board computer. The telemetry system transmits sound waves through a ranging tube to the water surface. The travel time is measured and converted into a tide stage height. Sound waves which calculate the tide heights are sent by a radio frequency to a receiver on board the survey vessel. This receiver displays the tide stage and has a RS-232 interface capable of supplying data to a PDP-8e computer system.

ON BOARD HARDWARE AND SOFTWARE. Recently the on board computer system was updated with a magnetic disk unit to increase data handling. Presently an evaluation is being conducted to determine the best method of handling the tide data once it is received on board. The ultimate goal is to make the on-site sounding adjustments in real time. This would give the survey party chief correct real time soundings from which to make various decisions throughout the survey. He presently makes real time adjustments when surveying in areas that do not require zoning. It is therefore a goal to create the same condition when surveying in zoned areas.

#### CONCLUSION

It is important to realize that a tide height read at one location may not reflect tidal condition at the survey site. This is due to a slope in the tidal datum and speed of the tidal wave. When it is necessary to provide accurate surveys with acceptable validity, it is advantageous to be familiar with the tidal characteristics which influence the surveys. By gathering tidal information for a short series of observations and performing the method of simultaneous comparisons, a tidal datum with a vertical accuracy of  $\pm 1'$  can be established. This accuracy is well within acceptable limits, however, there are many factors that influence the total vertical accuracy of a hydrographic survey. Accurately establishing an on-site tidal datum helps to refine the total surveying accuracy.

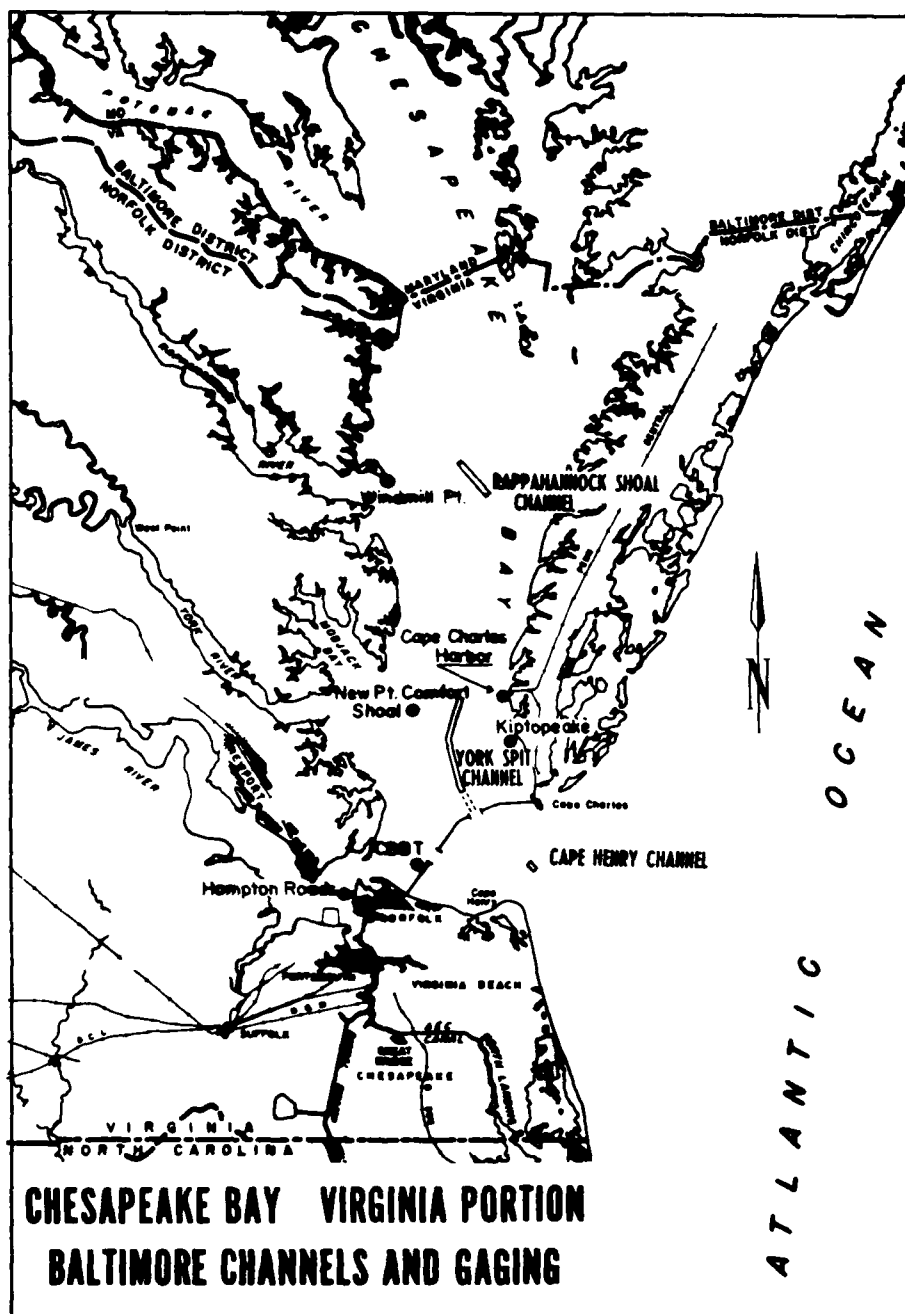


Figure 1

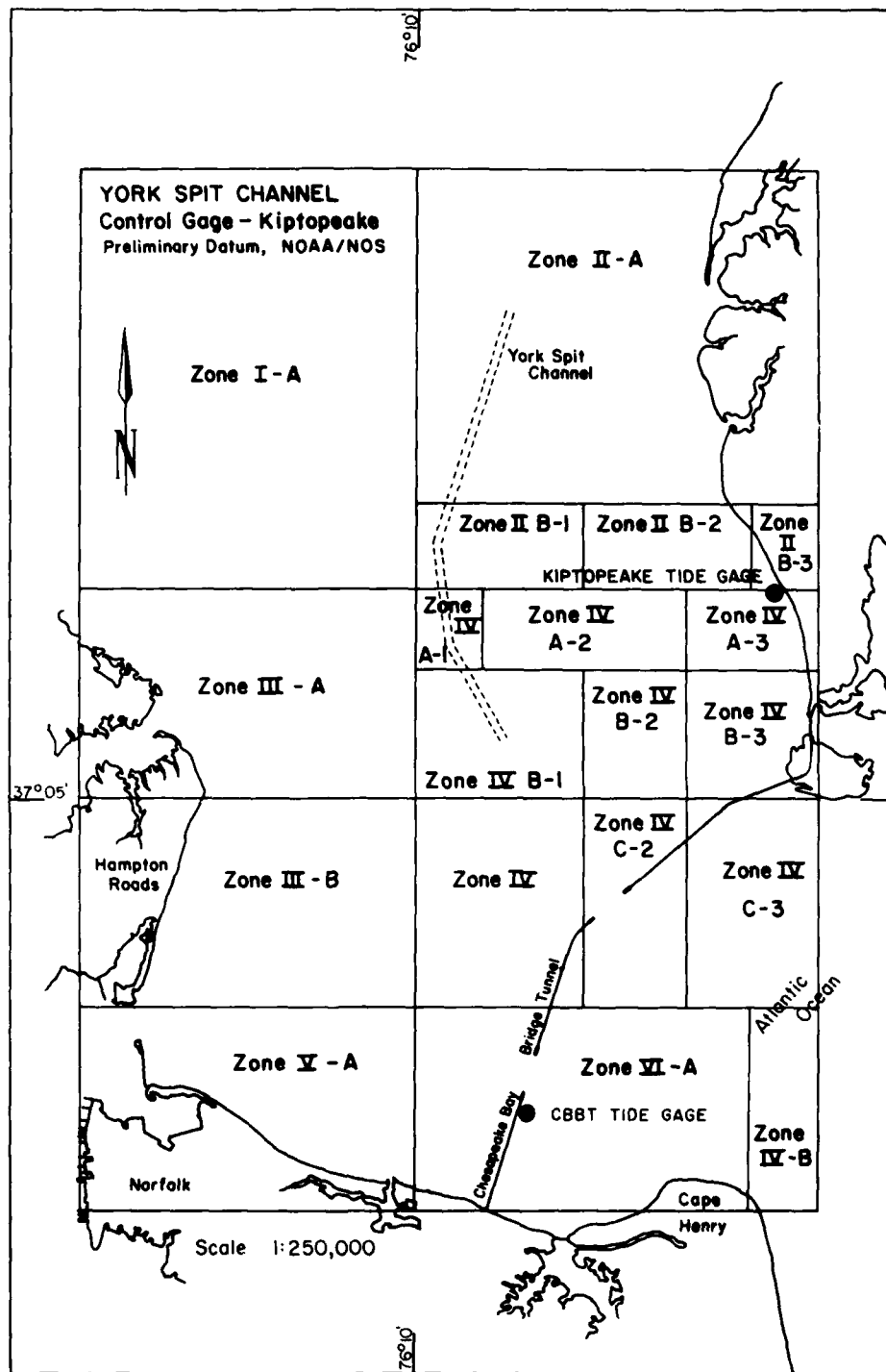


Figure 2

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A PORTABLE TIDAL DATA TELEMETRY SYSTEM FOR  
HYDROGRAPHIC SURVEYS

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BIOGRAPHICAL SKETCH

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ABSTRACT

Electronic technology has provided the hydrographic surveyor with the capability of obtaining real-time tidal information using acoustic gauges and telemetry packages which are portable enough to satisfy the requirements of day to day surveying at different work sites. These instruments feature small size, light weight and simplicity of installation. They can be easily transported and assembled by one man quickly enough to be practical for use at one or more tide stations each day.

INTRODUCTION

The Philadelphia District has the responsibility of surveying and maintaining some 500 miles of navigable waterways. These projects vary from shallow draft small boat projects and coastal inlets to deep-draft commercial channels. Because of the diversity of the projects, numerous survey procedures and a variety of equipment must be used to obtain survey data. The common denominator for all projects is the requirement for accurate tidal data to assure correct reduction of soundings. This paper will discuss a tidal data telemetry system used by District survey personnel to acquire this data automatically, in real time.

## GENERAL

It is a forgone conclusion that correct tidal reduction of soundings is critical in accomplishing accurate hydrographic surveys. Traditionally, the task of providing this information to the surveyboat has been the responsibility of the "tideman", who reads, records and transmits the data to the boat. This method leaves much to be desired. It is not efficient utilization of manpower and usually entrusts one of the most critical accuracy control factors to the lowest grade survey party member. Few, if any, alternatives offered in the past were acceptable substitutes.

Tidal curves, constructed from predicted tides, are only approximations of tidal time-height relations and are not sufficiently accurate for surveys which are conducted for the determination of channel conditions, dredging or engineering design.

The installation of recording tide gauges has not been practical, mostly because of the complexity of the installation, and the number of installations required to adequately define the tidal conditions on extensive navigation projects. The size of the gauges must also be considered. For the most part they are large and require elaborate installation, involving stilling wells, floats and wires or tapes to drive the recording mechanism. Most importantly, they cannot be set up quickly enough by one man to be considered portable on a day to day basis. In their usual configuration these gauges provide information that is recorded on either punched tape or inked or scribed paper records. Data is therefore available for after the fact correction of soundings, but not for real time reduction, which is an absolute requirement when working with automated survey systems. The gauges can be modified for telemetry by installing digital encoders, but this only adds another piece of equipment to an already cumbersome burden. Until recently, these were "facts-of-life" to be lived with and tolerated by the hydrographer.

## BACKGROUND

The system used by the Philadelphia District is the result of the "spin-off" from another tidal observation program which must be addressed to adequately define the development of the survey system.

In late 1979, the District Survey Branch was assigned the task of developing and installing tide monitoring stations at the easterly and westerly ends of the Chesapeake and Delaware Canal. The canal is a deep draft project connecting the head of Chesapeake Bay with the Delaware River, a distance of about 45 miles (72.4 km). Approximately 18 miles (29.0 km) of the route is land cut, in some places exceeding 100 feet (32.8 meters) from natural ground to the bottom of the channel. Tidal ranges at each end of the cut vary from 5.1 feet (1.55 meters) at the east end to 2.1 feet (0.64 meters) at the westerly end. The tidal characteristics are difficult to predict with any degree of accuracy due to the influence of the Susquehanna and Delaware River flows or conditions in the Chesapeake and Delaware Bays. Tidal heights are extremely important to mariners not only to assure adequate water depth to accommodate vessel drafts, but also because of the restrictive vertical clearances of the bridges and overhead natural gas pipeline crossing the canal. The purpose of the gauges was to provide this information to vessels through the dispatcher who controls canal traffic from the reservation office at Chesapeake City.

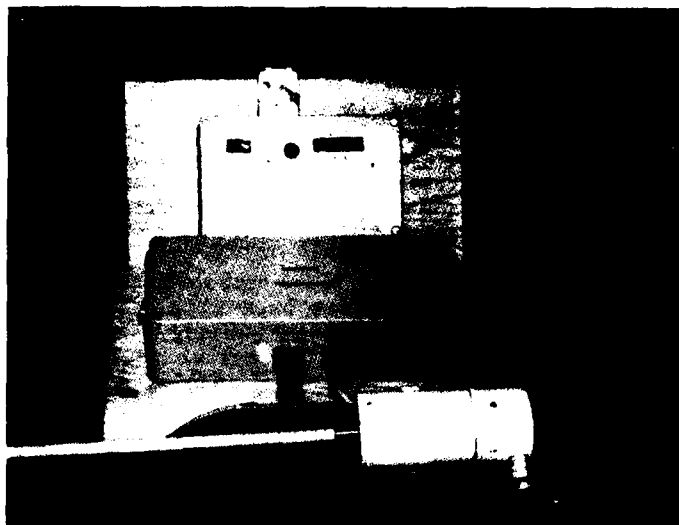
Several alternatives were studied to provide accurate, dependable data within a reasonable cost. During this analysis, the Aquatrak gauge, manufactured by Bartex, Inc., Annapolis, MD was selected as the tide measurement instrument because of its unique characteristics.

While developing the system for the canal it became evident that the Aquatrak gauge could be utilized in a portable telemetry system that would provide real time data to survey parties if it could be interfaced with a suitable telemetry package. The gauge was especially suited for this purpose since it overcame most of the problems inherent with previously available gauges. It was small, light in weight, internal battery powered, provided BCD output, and required minimal installation. Subsequent discussions with Bartex indicated that a practical system could be designed and built using for the most part stock components with suitable modifications and interfacing. A contract was awarded to Bartex for two systems which were delivered in late 1981.

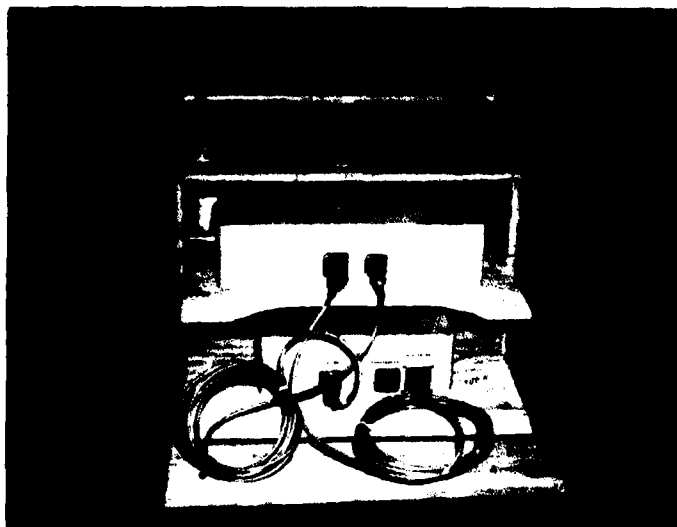
#### INSTRUMENT DESCRIPTIONS

Gauge Controller Assembly. The Aquatrak is an electronic gauge which measures water level by transmitting acoustic pulses from a transducer through a 0.5 inch (13 mm) tube to the water surface, comparing the surface reflected returns with those from a reference calibration and converting the pulses to distance. This distance can be displayed either as a distance from the water surface or can be converted to actual tidal heights by means of thumbwheel controls. The intervals at which the data is acquired are thumbwheel selectable with rates in minute intervals from 1 to 99 minutes. Data is displayed on an LED readout on the case in increments of 00.00 feet (0.00 meters) to 99.99 feet (30.48 meters), and is also available as a parallel BCD output for transfer to storage or data processing equipment. The stock gauge is powered by internal 12 volt DC rechargeable batteries or can be operated from a 120 VAC power source. The unit is 10.25 inches (260 mm) long, 6.25 inches (159 mm) wide, 3.50 inches (90 mm) deep and weighs about 10 pounds (4.54 kg). The sensor unit is 3.25 inches (83 mm) in diameter and 7.50 inches (190 mm) long and weighs about 1 pound (0.45 kg). The measuring pulse is transmitted through 0.5 inch (13 mm) diameter CPVC tubing of a length suitable for the individual installation. The standard connecting cable between the sensor and the gauge is 25 feet (7.62 meters) long. However, the length can be varied to suit the conditions; one permanent gauge on the Chesapeake and Delaware Canal is operating with a cable which is 210 feet (64.01 meters) long.

Transmitter Unit. The transmitter unit contains the internal power pack and the radio transmitter. A Motorola Series MT-500 portable radio is used to transmit the data acquired by the gauge. The standard gauge controller assembly has been modified to receive the telemetry interface in its original housing by removing the internal power pack. A larger power pack which provides both 15 volt DC power to the radio and 12 volt DC power to the gauge is mounted inside the transmitter unit. This power pack will operate the system for a period of about 5 days when sampling at a 5 minute interval. A charger is provided which will bring the power pack from full discharge to full capacity in about 16 hours. The unit housing is 14.12 inches (359 mm) long, 6.25 inches (159 mm) wide and 3.50 inches (90 mm) deep, and weighs about 16 pounds (7.26 kg).



Shore station components consist of processor, transmitter unit and sensor head.



Processor and transmitter units are mounted on sliding shelves in a wooden box for security and convenience of handling.



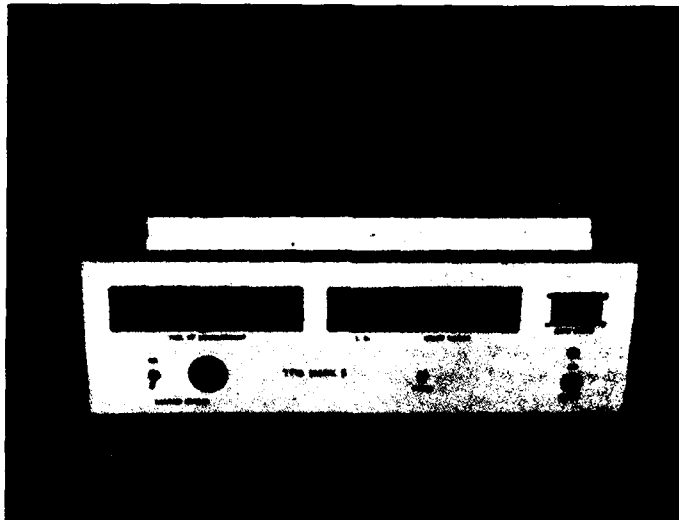
To eliminate interference between survey parties, the transmission range of the system has been maintained at the same distance normally provided by the radios for voice communication; about 5 miles (8.04 km) under routine conditions. This has been accomplished by using the same spring antenna that is normally provided with the radios. The range can be tailored to specific requirements by radio and antenna selection. As an example, a permanent installation on the Chesapeake and Delaware Canal is transmitting in excess of 12 miles (19.31 km) using the same type radio as the portable system equipped with a directional antenna.

Tidal Telemetry Interface. The ship board data is acquired by the tidal telemetry interface unit through a self-contained radio receiver and is available as either a visual display or a BCD output. Tidal data is displayed on an LED display with 0.5 inch (13 mm) characters which are easily read under normal light conditions. Four digits are provided for data resolution to .01 foot (3 mm). An identifier digit is included in the display in the event that more than one gauge is transmitting. In addition to depth, time is also displayed as hours, minutes and seconds, and is available in one of two selectable modes, either as a continuous real time display or as the time of the last depth sample. All displays are controlled by thumbwheel switches on the front of the unit. An audio alarm alerts the operator to each new reading. This alarm can be disabled by a toggle switch. BCD output to a printer or data processor is available through an RS-232 compatible plug at the back of the chassis. The components of the tidal telemetry interface are contained in a desk mounted chassis measuring 17.50 inches (444 mm) long, 16.50 inches (419 mm) wide and 5.75 inches (146 mm) deep, weighing about 14 pounds (6.35 kg). Power is provided from the vessel's 120 VAC electrical system.

Field Installation. As previously mentioned, the unit was designed to be portable, consequently installation has been kept to the minimum which assures that portability is maintained while providing accuracy and security.

The gauge and transmitter units are mounted on sliding shelves in a wooden box measuring 12 inches (305 mm) by 12 inches (305 mm) by 18 inches (457 mm) with a total weight of about 40 pounds (18.14 kg). The box is used not only as protection from the elements but also to provide some degree of physical security for the equipment by permitting it to be secured to the supporting structure with a chain or cable and lock. It also allows the person installing the gauge to carry all the components in one hand, providing a free hand for safety when disembarking from a boat to a pier or wharf. A simple wooden box was selected over a more elaborate housing to maintain a low profile for the equipment while left unattended.

In order to facilitate mounting of the sensor head, 3 inch (76 mm) I.D. PVC or ABS tubing is permanently secured to a piling at each tide station using stainless steel bands. A standard coupling is attached to the upper end of the tube. The sensor head fits inside the coupler and is supported by the shoulder formed by the tube inside the coupler. An elastic cord which is attached to the tube by hooks placed in holes drilled about 12 inches (305 mm) below the top of the tube secures the sensor to the tube.



Tidal Telemetry Interface: Displays time, tide and tide station identification on board boat.



Sensor Installation: Sensor head is mounted on 3 in. PVC tubing attached to piling.

The gauge is calibrated by reading a staff gauge at the site and adjusting the Aquatrak to these readings. The sampling interval is set and the gauge is operational. The procedure requires about 5 minutes to complete.

#### CONCLUSION

It must be recognized that the system being used is a proto-type, and improvements can and are being made. The manufacturer is currently working on producing a system with the gauging and telemetry components in one package. A shipboard receiver is being developed to use either 120 VAC or 12 VDC power for use on small boats with no AC power source as well as on board the larger AC equipped boats. These improvements are expected to be available in the near future and will increase the potential of the system.

The system has proven to be a practical and cost effective labor saving instrument. Applications are not limited to hydrographic surveys but can be expanded to include any discipline requiring real time tidal data.

TIDAL DATUMS FOR  
MEAN HIGH WATER LINE LOCATION  
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As a professional Land Surveyor in New Jersey, Maryland, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana and Texas, Paul T. O'Hargan specializes in tidal datum determination and near shore boundary location. He has lectured throughout the country and has published a number of papers on the subject. He is presently in private practice and is a Vice President of Craven, Thompson & Associates, Inc. in their corporate headquarters in Fort Lauderdale, Florida.

ABSTRACT

Tidal datums must be collected with more refinement for the accuracy requirements of a mean high water line survey than those required for construction or other purposes. This can be accomplished in a cost-effective way by using a tertiary gaging system reduced to a 19-year mean using secondary control reduced to National Ocean Survey primary control. From these tertiary or short-term studies, very short-term studies can be made to transfer the tidal datums to the vicinity of the mean high water line to be surveyed. Good accuracy can thus be accomplished without the need for geodetic levels.

INTRODUCTION

Mean high water (MHW) is, by definition, the arithmetic mean of high water heights observed over a specific 19-year Metonic cycle. (Tide and Current Glossary, 1975).

A mean high water line (MHWL) is the intersection of the water surface at the elevation of mean high water (Tide and Current Glossary, 1975). Since 19 years of observations are not available for all sections of the coast, simultaneous observational comparisons are made at intermediate stations, in order to derive the equivalent of a 19-year value (Marmer, 1951).

In many areas of the country, the coastal shore has a very small gradient and, thus, a small difference in the elevation of mean high water can make a large difference in the horizontal placement of the mean high water line. Therefore, every effort must be made to obtain the best equivalent of a 19-year value for the elevation of mean high water on a site of a MHWL Survey.

Mean high water must be determined at the exact site of the mean high water line survey as the tidal water surface is not a plane, but undulates along the shore (Guth, 1974). A tidal

datum determined on one side of an island can be a different elevation on the other side of the same island. Also, drastic changes in the elevation of MHW can occur as the tide enters an estuary from the ocean (Reimold, 1974).

#### TIDE STATIONS

A tide station is the geographical location at which tidal observations are conducted, and also the facilities used to make tidal observations. These may include a tide house, tide gage, tide staff and tidal bench marks (Tide and Current Glossary).

Primary Control Tide Station. This is a tide station at which continuous observations have been made over a minimum of 19 years. The data series from this station serves as primary control for the reduction of a relatively short series from subordinate tide stations through the method of comparison of simultaneous observations (Tide and Current Glossary, 1975).

Secondary Control Tide Station. This is a tide station at which continuous observations have been made over a minimum period of one year. The series is reduced to an equivalent 19-year value by comparison of simultaneous observations from a primary control tide station (Tide and Current Glossary, 1975).

Tertiary Tide Station. At a tertiary station, continuous observations have been made over a minimum period of 30 days. The series is reduced to an equivalent 19-year value by comparison of simultaneous observations from a secondary control tide station (Tide and Current Glossary, 1975). Of course, if the tertiary station is in the vicinity of a primary control tide station, the comparisons can be made with that station.

Very Short-Term Tide Station. This is one or more locations on the subject property, where the tide has been observed simultaneously with a tide station for which a MHW value has been previously computed. It has also been referred to as an extrapolated water elevation point or EWE point. There are various types of very short-term tide computations and the observations vary depending upon the type selected.

#### VERY SHORT-TERM TIDE STUDIES

In order to make a very short-term study, a tide station must be available in the vicinity. This type of datum determination is not a substitute for a secondary or tertiary tide study. It is intended to extend the datum established by the standard method at a tide station to the site of the mean high water line survey.

Range-Ratio Method. This is also known as the National Ocean Survey standard method. A tide staff is set waterward of the MHW line to the extent that a full range of tide can be observed. It is not used by the author in heavy vegetation as, although the undulations of the tide will be addressed, any friction loss of the tide as it passes through heavy

vegetation will not be addressed. A series of observations are made from before a low or high water until after the following high or low water at both the project site and at an appropriate tide station where datums are known. The computations are as follows:

R = Range on day of observation  
 MR = 19-year equivalent mean range  
 MHW = 19-year equivalent mean high water  
 MLW = 19-year equivalent mean low water  
 TL = Tide level on day of observation  
 MTL = 19-year equivalent mean tide level  
 c = At control station  
 p = At project staff

1.  $MR_p = R_p \times MR_c / R_c$
2.  $MTL_p = TL_p + (R_p / R_c) (MTL_c - TL_c)$
3.  $MHW_p = MTL_p + MR_p / 2$
4.  $MLW_p = MTL_p - MR_p / 2$

Extrapolation by Time. This method was developed by Captain Jack E. Guth (Retired U.S.C.G.). It consists of a series of simultaneous comparisons of tidal observations made at a tide station at which datums are known and at tide staffs set just immediately waterward of the mean high water line on the project site. Using the time difference of high tide at each location as a function of time of mean high water (MHW), we are able to arrive at the elevation of MHW at the project. This may be arrived at graphically or by computation as follows:

5. Tide difference (t) = time of  $HW_c$  - time of  $HW_p$
6. Time of  $MHW_c$  rising tide - t =  $t_{1p}$
7. Time of  $MHW_c$  falling tide - t =  $t_{2p}$
8.  $MHW_p = \frac{1}{2} (\text{water elevation}_p \text{ at } t_{1p} + \text{water elevation}_p \text{ at } t_{2p})$

The simultaneous observations must be made every three minutes from before MHW on a rising tide to after MHW is reached on the falling tide.

Alternate Method by Time. This method was developed by O'Hargan and Guth independent of each other. The observations are the same, but they are then plotted in graph form. The time span is determined from the graph of the control station, that is the difference in time from the occurrence of MHW on the raising tide to the occurrence of MHW on the falling tide. This same time span is placed on the graph of the project tide readings and the elevation is scaled from the graph where the time span touches the tide plot.

Delta Height Method. This is the most cost-effective method, as only the elevation of a particular high tide need be known.

This high tide can be determined by standard crest stream gages set on project site and at the tide station. Then:

HW = High water on day of observation.

$$9. \Delta h = HW_C - MHW_C$$

$$10. MHW_p = HW_p - \Delta h$$

Amplitude-Ratio Method. George Cole, former Chief of Florida's Bureau of Survey and Mapping, developed a method of very short-term tide studies that works well when the shape of the tide curve, near high water, is not the same at the project site and control station (Cole, 1981).

Cole's method was then somewhat modified by Bernard Zetler, of Scripps Institute of Oceanography (Zetler, 1981). In this method, the tide is observed from one to three hours before and after a high tide and an observation is made at the control station to determine the elevation of the proceeding or following low tide. The observations are graphed and the time span of two, four or six hours is plotted. The difference in height between the time span line and high tide is "A".

$$11. R_p = A_p/A_C \times R_C$$

$$12. MR_p = A_p/A_C \times MR_C$$

$$13. MHW_p = (HW_p - R_p/2) - (TL_C - MTL_C) + MR_p/2$$

#### DATUM DETERMINATION

The ultimate goal is to have one or more tide staffs referenced to bench marks along the mean high water line to be surveyed without having run geodetic levels. First, select the form of very short-term study to be used. The author uses the Delta-Height Method, where control is available nearby in the same body of water, and the Amplitude-Ratio Method, where control is somewhat distant or in an adjoining water body.

If no control is available, the site is occupied with a recording tide gage and a recording tide gage is set at the site of the nearest primary or secondary control station. The study is reduced to mean values, the 19-year equivalent of mean high water, by simultaneous comparisons (Manual on Tide Observations, 1977 and Marmer, 1951).

Tide staffs are then set just waterward of the estimated MHWL at an arbitrary elevation and are referenced to bench marks. The staff and control station are observed as outlined for the various methods, on at least two occasions and the elevation of MHW on the staffs is computed and referenced to the bench marks. For example, if a staff reads upwards from ten feet at ground level and the bench mark is leveled in at, say, 12 feet and MHW is computed to be at 10.5 feet on the staff, then the bench mark is 1.5 feet MHW.

The zero contour based on this bench mark, in the vicinity of this bench mark, is then the mean high water line and it can be located by standard surveying procedures and mapped by standard methods. The author then prefers to plot points of MHW on controlled aerial photography and then to connect these points with a smooth line by following the tone and texture (signature) of the photograph.

#### CONCLUSION

The location of a MHWL requires accurate tidal datums along the line itself, due to undulations in the tide and friction encountered by the tide as it progresses from the open water to the mean high water line. Very short-term tide studies are cost-effective to accomplish this goal, as they generally require only two days of observations.

If the tidal datums are not available in the area to control the very short-term studies, a tertiary tide study reduced to mean values by comparison with a secondary station will be the most cost-effective method, as the times of observation are reduced from a year to thirty days. Of course, if a secondary station is not available and, if the nearest primary station is a great distance away, then a secondary study would be required.

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SESSION V: HYDROGRAPHIC SURVEYING - MISCELLANEOUS TOPICS



Glenn Boone  
Wilmington District  
Chairman  
(also Speaker)

*Speakers*



Dave Sims  
Portland District



Bill Berkemeier  
CERC

NOTE: David Pearson, Science Applications, Inc., also speaker. Picture not available.

## SESSION V

### HYDROGRAPHIC SURVEYING--MISCELLANEOUS TOPICS

#### Summary

This technical system encompassed a wide range of subject areas within the general scope of hydrographic surveying. Mr. David Pearson discussed the development and application of a microprocessor-controlled, compact, high-speed survey/tracking system which was operated on a small boat in the Portland District. Mr. Dave Sims reported on the operational characteristics of the survey boat RODOLF--the result of both sea trials and actual surveying situations. Mr. Glenn Boone presented some preliminary data on microwave calibration results and suggested a possible calibration procedure based on these data. And finally, Mr. Bill Birkemeier described the survey equipment and surf zone surveying methods employed with the Coastal Research Amphibious Buggy (CRAB) at the Coastal Engineering Research Center (CERC) Field Research Facility, Duck, N. C.

A MICROPROCESSOR BASED SURVEY  
TRACKING AND CONTROL SYSTEM  
FOR SMALL SOUND BOATS

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BIOGRAPHICAL SKETCH

David Pearson is presently employed as a Senior Staff Engineer at GOULD Inc., Ocean Systems Division, located in Aquidneck Industrial Park, Middletown, R.I. 02840. In this capacity he is responsible for applying modern digital technology to the complex problem of undersea vehicle control. He has previously been with Science Applications, Inc., where the systems described in this paper were developed and prior to that at the Naval Underwater Systems Center, Newport, R.I. Mr. Pearson received a B.S.E.E. from the University of Rhode Island in 1967 and has since studied electronics, computer science and ocean engineering.

ABSTRACT

The Portland District of the U.S. Army Corps of Engineers has had a continuous requirement for a compact, high speed survey/tracking system for hydrographic surveying from small sound boats. Recently two such systems were developed by Science Applications, Inc. and installed aboard the sound boats TRAVELER and HERON. These systems employ state of the art microprocessor based computers and are capable of most functions previously found only on larger, more expensive installations. The Portland District conducts high speed, parallel to channel axis surveys and has a number of requirements which can only be satisfied by a full feature system which must be installed in limited space and operated under harsh conditions. The systems described have been in daily operation since June 1981. Their use has improved the accuracy and efficiency of the Portland District's survey operations.

## INTRODUCTION

In the past decade modern computer equipment, integrated with precision microwave ranging systems, has greatly improved the accuracy of bathymetric surveys. It is now possible to set to sea in the morning with the capability to prepare a detailed survey, perform 70 track miles or more of the survey and return in the evening with data logs, smooth sheets and contour maps of the area. This capability has been realized aboard medium and large survey ships utilizing sophisticated minicomputer\* systems. On smaller survey vessels, such as the sound boats performing channel condition surveys of estuaries and inland waters, these complex systems are often too large and environmentally sensitive to be employed.

Sound boats with lengths under 40 feet have requirements at least as stringent as larger vessels operating in open water. In order to produce hydrographic charts of sufficient accuracy to monitor changes in channel depths and to perform volume difference calculations it is necessary to sail reproducible survey lines. Under the best conditions this is difficult unless a rapid update of positional error and a responsive helm are maintained. Without this control it is impossible to do this on narrow, winding, congested waterways at speeds exceeding 10 knots.

The Portland District provided two of their smaller soundboats with a capability for survey control approaching that previously found only on larger vessels. In June 1981 the "TRAVELER" based in Portland and the "HERON" at Coos Bay, Oregon were equipped with microcomputer survey systems capable of performing many of the functions of the more complex and expensive systems, but requiring less space, power and environmental control. This paper describes those systems in general and the hardware and software features which make it possible to provide the required capabilities with a microcomputer based system in particular.

Modern microcomputer systems are functionally similar, to larger conventional computer facilities except that they are slower, have less memory addressing capability, smaller data widths and, in general, have limited peripheral capability. They do however perform all of the basic addressing, arithmetic, logical and input/output functions required of any general purpose digital computer. The system described in this paper is unique in that it takes advantage of the architecture of the microprocessor and tailors the hardware and software to the survey application, thereby realizing the necessary computational speed and accuracy.

## SYSTEM DESIGN

The heart of the survey system is a Zilog MCZ-1/05 microcomputer. The programming is done in FORTRAN IV with the exception of interrupt handlers and input/output routines which are coded in assembly

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\*Minicomputer refers to the class of digital machines occupying a limited space (generally one rack or less) and employing a relatively large number of integrated circuits (IC's), which when interconnected, provide all addressing, processing, input/output, memory and related computing functions. A microcomputer provides addressing and processing on a single IC with a limited number of IC's performing the remaining computing functions.

language. This equipment was selected for its powerful instruction set, vectored interrupt capability, family of support circuits and commercial quality packaging. The availability of a Zilog floppy disk development system MCZ-1/20 provided an excellent vehicle for software design and checkout.

Hardware. The equipment in this system also includes; a Houston Instruments DP-1 plotter and PTC-5B controller, a Lear/Siegler ADM-3A video terminal, a Centronics Pl line printer, and Memodyne M-80 cassette recorder. These units were shock mounted in a standard 19" rack with an overall height of 42". Upon installation this equipment mounting was modified slightly for the sake of visibility. Connections were made for input from a Corps supplied Del Norte microwave ranging system and an output to the marking circuitry on a Ross fathometer.

Power required for the system is 120 VAC at less than 1 kw. A single on/off switch mounted at the front of the rack facilitated equipment start-up. The procedure is to turn on system power, place a cassette program tape in the recorder and press the processing unit RESET button. The program will load from tape and run. The application programs perform all operator communication via the video terminal. A user friendly environment is realized by the extensive use of operator prompts and input parameter checking.

Central Processing Unit. The heart of the MCZ-1/05 microcomputer is a Z-80 microprocessor. The Z-80 is one of the most sophisticated conventional 8 bit processors available. The 158 instructions, dual register set and hardware vectored interrupt capability combine to provide the throughput necessary to perform realtime navigation. A full complement of memory (65 kilobytes) resides in the MCZ-1/05 along with all necessary I/O interfaces, power and cooling requirements.

Memory. The memory is partitioned with respect to both hardware and software for use in this particular application. A monitor program burned into read only memory (ROM) occupies the first 4 kilobytes (kb). This monitor provides all hardware initialization for the video terminal, input/output interrupt, timekeeping and peripheral devices. In addition, the first stage of a bootstrap loader is contained in this monitor. At start-up the RESET button on the MCZ is depressed which causes the processor to transfer control to a location in the monitor. This program will, after initializing the Memodyne serial interface, rewind the cassette, move the tape to the load point and input the first, short, fixed length record to random access memory (RAM). Upon completion a jump to the code just loaded is performed. This code is the second stage of the bootstrap loader and contains all necessary information to load the remaining RAM with the program on tape. This technique allows a number of application programs to be used simply by loading different tapes. The programs need not be constrained in length or memory use since they each have a unique second stage bootstrap. In addition program modifications may be made at a central facility utilizing a large development system having the capability of compiling and linking FORTRAN. Memory images of the programs may then be down loaded to cassette and mailed to the user.

Development of program code of the complexity required for geodetic calculations, can best be done in a high level computer language. The MCZ family of microcomputer products offers a disk based FORTRAN which is suited to the system concept. It was desirable however to devise a method of linking the various user programs to the FORTRAN support software. The usual operation of the disk based system was to load the

required library routines each time a program was to be run. Since this library can take up to 12 kb of memory substantial time and cassette tape would be necessary to store complete program images. A method was devised where specific areas in memory were assigned to each library routine and to their related variables. The MCZ disk based system allows force loading of FORTRAN code and data anywhere in memory. The library was burned into ROM at specified addresses, then a properly linked user program could vector to these addresses. To load and run a program it is now only necessary to load the unique user code and jump to that code\*.

The ROM also contains the standard Zilog line printer driver which had not been designed to operate from ROM because of the mixing of fixed and variable code. As part of the start-up initialization procedure this code is moved from ROM to RAM thereby allowing a standard driver to be used without loading it each time. This is admittedly wasteful of computer memory space (1 kb) but considering the limited number of systems to be produced and the cost of developing a new line printer driver, such a technique was considered reasonable. The routine to accomplish this block memory transfer is extremely well suited to the Z-80 instruction set and requires only 4 lines of code and 11 bytes of memory.

Input/Output. The configuration of the various channels providing communication between the processor and peripheral devices was carefully designed to optimize data transfer rates. The primary design criterion was to not suspend processor operation while awaiting data or a peripheral response; if suspension is necessary its duration should be minimized. The vectored priority interrupt system of the Z-80 provides an excellent structure to meet these requirements. For the purposes of the following discussion the counter timer chip (CTC) which performs the real time clock task will be considered a peripheral. The CTC is in fact architecturally similar to the parallel input/output (PIO) chip and all vectored interrupts in the system are generated by one or the other of these devices.

The priority of the peripherals which are allowed to interrupt the processor is as follows (from highest to lowest):

- Real time clock (10 millisecond rate)
- Plotter interface (when stack clears)
- Microwave ranging system (each update)

The other peripherals are simply set to operate at high BAUD\*\* rates and programming techniques are used to maximize data transfers. These other peripherals include the cassette recorder which transfers data at 9600 BAUD and is of little concern in any case since delays here would only effect program load times and not real time execution. The remaining two devices are the video terminal having a serial channel set to 19200 BAUD and the line printer which is a parallel interface. Maximum processor execution rates are required when the survey is

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\*Because of limitations on version 3.0 of Zilog's FORTRAN library it was also necessary to load some of the operating system to communicate with the standard console driver. This is to be corrected in version 4.0.

\*\*BAUD rate is a standard measure of serial data transfer rate. Approximately one-tenth of this value equals the number of alphanumeric characters per second.

being conducted because the helmsman aid information must be updated on each program cycle. At that time only left/right error and distance to go is displayed on the console and when necessary one line, without a leading line feed, is printed. This minimizes transfer times by limiting the length of the transfer to the console and not having to wait for a mechanical line feed delay in the case of the printer.

The operation of the real time clock, plotter and ranging system proceeds in the background with minimum effect on processor execution time. Typically a number of commands are sent to the plotter interface, followed by an instruction to perform this series of commands and notify the processor upon completion. The processor then sets an internal flag indicating no further plotter commands are to be sent until this completion occurs. During the time these operations have been progressing one or more ranges may have been received and the real-time clock routine will have been updated a number of times. When range data is transmitted the processor immediately vectors to an input routine (assuming it is not already performing an interrupt routine of higher priority) to save this data in memory and set a flag which the high level program can check. If an interrupt from the CTC, which provides the real-time-clock, is received (once every 10 milliseconds) the processor is immediately vectored to a routine which updates the ten millisecond counter and after ten updates the hundred millisecond counter and after one hundred updates the one second counter...etc. The real time clock performs this procedure up to incrementing the day once each 24 hours. This counter is the highest priority interrupt and will be vectored to even if a lower priority interrupt handler is in progress.

These techniques provide for input/output communications to proceed more rapidly than the electrical and mechanical constraints of any individual peripheral would allow. In operation the system will often be observed plotting and annotating a position, while simultaneously producing a printed line and updating the cross track error on the video display.

The significance of this is that not only are the observable peripheral communications proceeding at the maximum rate but also the solution to the navigation problem is being accomplished within one second. The navigation cycle time of one second was a design specification since that is the standard microwave ranging update time. For good control (a responsive helm) the time from an actual position to providing the helmsman with information based on that position must be minimized. Experience indicates that at typical boat speeds, this time must be no greater than a few seconds and a more rapid update makes better control possible.

Video Terminal. A Lear-Siegler cathode ray tube video terminal was chosen for the operator console. This unit displays 24 lines of 80 characters each. Special codes allow erasing the complete screen and specification of cursor position. The video and standard typewriter style keyboard are packaged in a rugged case of high impact plastic which is mounted on an aluminum shelf in the system enclosure. The RS-232-C serial communications line operates at 19200 BAUD in a full duplex mode.

During operation of the survey set-up program and start-up of the real time navigation program the user is prompted for required information. The information may be entered as a number, when required, or as a "Y"

or "N" when a yes/no decision is needed. When numbers are entered they may be in an integer form, a real number with decimal and fraction or in FORTRAN scientific notation (e.g. 6.34E-10). The input is scanned to identify syntactic errors and re-prompt when necessary. This provides an overall "user friendly" man/machine interface which an untrained operator may rapidly adapt to.

Digital Cassette Recorder. A Memodyne M-80 cassette recorder is used for program storage and loading. Interface is via an RS-232-C line operating at 9600 BAUD. Bidirectional communication in the half duplex mode with request-to-send/clear-to-send handshaking is implemented.

During system initialization commands are sent to the recorder to rewind the standard digital Phillips cassette, move it to the load point, input the second stage bootstrap and then proceed to load whatever program is located at that position on the tape. The ANSI compatible tape format provides the capability of supplying two user programs per tape. Loading the other program is accomplished by simply removing the cassette, flipping it over and reinserting it. The two user programs supplied to the Portland District (survey set-up and real time navigation) are recorded on each tape. In practice the operators have found it is most efficient to use two tape copies, one copy for loading the set-up program and the other for the navigation program. This eliminates the need to wait for a tape to rewind for its total length (about 30 seconds).

The capabilities of this recorder allow future expansion of the features of the survey system. If it is desired to record navigation parameters or depth data (if digitized) no hardware modifications to the recording interface are necessary. The input/output software has been implemented and checked in the output mode as well as the input mode. Therefore the only modifications are to high level software and I/O driver linkages. The ANSI tape format allows playback at many permanent computer installations thereby facilitating automated post survey analysis.

Plotter. The roll chart plotter used in the system is a Houston DP-1 with a PTC-5B controller. The two way RS-232-C serial interface operates at 300 BAUD and input is under interrupt control as previously described. Line plotting and alphanumeric data is communicated from the processor to the plotter controller stack. This stack fills since the mechanical constraints of the plotter preclude continuous operation at the 300 BAUD rate. The user program is designed to output a command to clear this stack from time to time while the processor is engaged in other tasks. This handshaking process in which the interrupt system awaits a special code from the plotter assures that no data will be lost due to overfilling the stack. The overall system efficiency is greatly improved since the processor can perform non-plotter related tasks while the mechanics of plotting progress.

Printer. A Centronics P-1 microprinter provides a log of all pertinent data. The copy is produced on a roll of aluminum finish electrostatic paper. During set-up all parameters pertaining to the chart size, scale, survey tangents and offsets are logged.

During analysis of the completed survey data any set-up information which may be questioned can be verified. The real time navigation program logs the followings data at the time of each fix.

- Sequential Fix number



- Date of survey
- Time of Fix
- Values of the two ranges used for computation (feet)
- Values of the coordinates in either an x/y (feet) or Lat/long (degree-minutes) systems.

Post survey analysis may uniquely correlate a particular fix number appearing on the survey track with the available data on the printout. This provides a means of resolving, with precision, the time or location of the sound boat within any specified fix interval.

Software. The high level code used in this system is Zilog's version 3.32 of FORTRAN which is based on the ANSI X3.9-1966 standard. All projections, geodetic positions and navigation parameters are computed at this level as well as editing, plotting and formatting of console input/output. The only functions coded at the assembly language level are I/O drivers, interrupt handlers and the real-time clock. An important feature of this FORTRAN is the complete support of double precision floating point arithmetic including array storage and library functions. The system uses, double precision data and operations, which have a precision of 14 significant digits, where required for global positioning. In general the standard single precision (7.5 significant digits) is not sufficient to maintain 1.0 meter accuracy over the surface of the earth\*.

Survey Set-up. The program which provides the system operator with the ability to prepare a chart, specify survey lines and establish radio navigation control points is named "SET-UP". A tape labeled SET-UP is loaded after powering up the system and the console will begin prompting the operator for various survey specifications.

Two lines, of up to 24 characters of alphanumeric data each, are initially requested. This data is referred to in the prompt as survey "title" and "date" and has no effect on program operation. This information is only used in the labeling of records produced by the system.

Next the operator is prompted for a desired chart projection. The choices are State Lambert, UTM, or Local\*\*. If State Lambert is selected, the system will prompt for the north or south Oregon zone, whose parameters are stored in internally, or for "other". If other is selected a set of constants for the desired projection must be input. Selecting the UTM option will require the input of a central meridian and choice of the north or south hemisphere. The Local projection requires no further information since all parameters are computed from chart center and known ranging system coverage.

The system will proceed to request information concerning the selection of input/output units and charting parameters. At this point the operator specifies either an x/y grid system in feet or a latitude/longitude grid in degrees and decimal minutes. Once selected

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\*A minimum of 9 digit precision is required to provide sufficient accuracy for continuous global navigation with careful attention to the data base structure.

\*\*A Local projection is an S.A.I. developed form of the Lambert projection which provides extremely high accuracy over the maximum microwave ranges. For internal computations (baseline, circular solutions and ship velocities) this Local projection is used.

all further input and output on the console and output at the printer and plotter will be in this system. The chart origin, physical length in inches, scale, grid interval and rotation of the grid from true north are now input. The chart may be rotated from zero to plus or minus 90 degrees. This allows the chart to have a lengthwise axis parallel to any desired survey line. All information necessary to produce a chart has now been entered and the plotter begins operation. A border, label, grid line segments at the borders and line intersections are produced with grid annotations along the borders. Because of the plotter interface interrupt system previously discussed the console will resume prompting the operator sometime prior to completion of the chart. Specification of the tangents and offsets for the desired survey are required next. Coordinates of the starting and ending points of the first central tangent are input.

The numbering system which uniquely defines each survey line and the desired direction of travel along that line should be discussed at this point. This system will be used subsequently in the real time navigation program to identify lines input at this time. The identifying number for any line in the survey takes the form T,O,D where T is the number of the central tangent in the order it is input. This positive integer begins at 1 and may go as high as 15 (the maximum number of tangents in a survey). The second digit O identifies the particular offset associated with a tangent. The offset may take a value from zero (central tangent) to 10 (the maximum number of offsets for each tangent). The final digit D will specify the direction of travel along the tangent or offset and must have the value +1 or -1. A +1 will indicate travel from the specified starting point to the ending point of the associated tangent. If during the performance of the survey the operator wished to travel from the start of the first tangent to its end and then return on a parallel offset which had been specified immediately following that tangent he would indicate this by first selecting line 1,0,+1 and then 1,1,-1. This data base allows rapid selection of any line within a survey.

The coordinates of a central tangent are input followed by the offsets in feet. An offset is specified as the distance to the right or left, plus or minus respectively, of the associated tangent. The offsets may be input in any order and will be parallel to their associated tangent and of the same length. After a tangent and its offsets have been input the system will ask if it is desired to plot these survey lines on the chart. An affirmative response will cause the plotter to begin operation. While the plotter performs its task the console will request specification of the subsequent tangent and its offsets. This process will continue until all desired survey lines are input or the capacity of the system is reached. If any individual tangent or offset has one of its end points outside of the chart border no attempt will be made to plot it.

Upon completing the input of the parameters describing the survey the computer will query the operator as to the need for plotting individual points. An affirmative response will allow the input of coordinates for a point and the selection of moving the pen to that point in either an up or down position. This provides the capability of plotting lines as well as points on a prepared chart. Additionally, each point may be annotated with up to 24 operator selected characters. This ability to plot survey related points and lines is especially useful for indicating geodetic calibration marks, microwave beacons, transponder baselines and channel boundaries. This information, once it has been plotted, is not retained by the system. The final stage of the SET-UP

program is specification of the microwave transponder (remote) locations.

At least two and up to four remotes may be specified.\* A relationship exists between each particular remote and its input number 1 thru 4. There is a one for one correspondence with the selector switches on the front panel of the Del Norte control unit. Care should be taken when specifying the remote locations to assure that the selected remote, is in the desired position. For each remote an elevation will be requested so that true horizontal ranges may be calculated. The final item required is the elevation of the shipboard transceiver after which the system will request that the real time navigation program be loaded.

Unless otherwise noted all parameters in the preceding discussion are retained in a common area of computer memory for use by the navigation program. Prior to loading that real time program the power to the system must not be interrupted. An overlay structure for the data areas of the SET-UP and NAV programs provide all necessary links for the survey, remote charting and projection specifications.

Real Time Navigation and Control. The program which performs all real time navigation computations, ranging input and data output is named "NAV". The tape labeled NAV should be loaded immediately after completing the SET-UP program. Since the majority of information required by the program will already be resident in the computer because of having run SET-UP a minimum amount of data will need to be input. The first prompt will be for the operator to input the present time. This will be the time to which the real time clock is synchronized. Any datum may be used (local, daylight savings, Greenwich, etc.) and will appear on the listing of fixes generated by the line printer.

The system will automatically check to determine if the ranging equipment is connected and receiving two depths. If it is not a message to "TURN ON DEL NORTE" will be displayed on the operators console until such time as this condition is met. In the case where the system is turned on and a survey is set-up at dockside and this location is not within sight of the remote locations it may be necessary to transit to the operating area for the program to continue. This self test feature is useful when different ranging control units and/or cables are used each time the system is deployed.

The only other operator input required is the specification of the fix interval. A fix is defined as the point in the program where; the ship track is marked with an "X" and annotated, the fathometer is marked, and a printout (previously described) is produced. The navigation parameters, ship track and operator console are updated at the 1 second ranging rate at all times. The fix interval may be specified as a time, in seconds, or as a distance, in feet. The minimum in either case is one unit. The ability to specify this interval as a function of distance traveled is particularly useful. The distance criterion is to "fix" at the first navigation cycle which indicates that the radial distance from the previous fix is equal to or has exceeded the specified interval. This method of calculating the interval normalizes

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\*If less than two stations are input the real time navigation program will indicate that insufficient data is available for a solution. At that time, however, the specification may be made via the special function keys.

the physical distances on the ship track plot with respect to variances in speed and control along the desired line.

The main navigation cycle begins with a number of default conditions. These defaults have been chosen to minimize the need for operator intervention. Any of the default conditions may be changed by means of the special function keys described later in this report. At start-up the following conditions exist.

- a. The plotter is enabled with the pen up.
- b. The printer is enabled.
- c. The operators console is in the transit display mode.
- d. True north is being used as a reference for course made good and bearing displays.
- e. The speed criterion for determining valid range data is set to 30 knots.

This system status will cause the navigation calculations to be performed, the plotter pen to go to the proper position but not mark and the display to indicate position in units compatible with the selected projection. At the chosen fix interval the plotter will mark the vessel's position with an "X" annotated with the fix number, the printer will record data in units compatible with the chosen projection and the fathometer will be marked.

This system default status may be modified by the use of special function keys at any time. This program has been designed to allow the use of these keys without interruption of the ongoing navigation cycle thereby providing an ability to dynamically reconfigure the system without halting the display, plotter and most important, the real time control of the boat. The special functions all consist of two alphanumeric characters, optional numeric parameters when required and a carriage return. The line is input and the function performed at the time of the carriage return. As an added feature the complete menu of special functions available may be displayed upon depressing the ESCape key. This interrupts the current operators display, it does not however disrupt the ongoing track plot.

The most important special functions include the following:

- Change to or from time/distance interval modes and specify interval.
- Enter a magnetic correction in degrees to be applied to all subsequent headings and bearings.
- Select the solution on the alternate side of the baseline\*.
- Modify the maximum speed validity criterion (knots).
- On console display;
  - Latitude/Longitude of position
  - State Lambert X/Y position
  - Local/Grid X/Y position
  - Two microwave ranges being used
  - Average speed/course made good
  - Range and bearing to a destination
- Enter, display or plot a destination.
- Take a sample "fix".

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\*Upon start-up an arbitrary choice of the two available solutions is made by the system. At this time a change may be desirable. Once navigation has begun subsequent solutions are chosen based on previous positions. With proper selection of remotes the correct solution will always be used.

- Enable/Disable the printer, plotter or fathometer mark.
- Raise or lower the plotter pen.
- Enter new remote data (remote #, position and elevation).
- Change from transit to survey mode or back.
- Select new tangent and offset survey line to navigate along.

The last two items are of interest and will be used as an example of the operation of this program. Upon entering the navigation cycle as described, the vessel proceeds to the area of the start of the survey. During this time the first line to be surveyed is entered via the special function keys "T0" (tangent/offset). Assuming a three tangent survey is to be performed from the opposite direction from which it was entered in the set-up program the keystrokes would be as follows; "T03,0,-1" indicating tangent number 3, central tangent (i.e. no offset), negative direction from set-up entry. At this time the destination location stored in the system is set to the start of this line and range/bearing information to that point may be displayed by the special function "I6" to assist in initial positioning of the sound boat.

The operators display up to now has been in the "transit" mode, it may be changed to the "survey" mode via the special function "CM" (change mode). The display now provides an indication of the left (-)/right (+) error and the distance to the far end of the chosen survey line in the direction of travel. The boat may now proceed down the survey line rapidly with maximum control since the error information is updated at a one second rate.

The navigation system operator should select the next survey line while progressing down the current line. For this example it would probably be "T02,0,-1". The carriage return is not pressed until the current tangent is complete. When it is, the line of data is entered and the error display is referenced to the new line. This method allows the sound boat to travel up and down the desired survey lines at the maximum rate under system control at all times.

During conduct of the survey if baselines must be crossed it is only necessary to switch the display on the Del Norte to the desired pair of transponders as the baseline is approached. This notifies the system that new remotes (and baseline) are now in use, the necessary updates are made and navigation proceeds. The initial solution chosen with respect to this new baseline is that closest to an average of the previous ones. The features described here and others which may be employed when unusual conditions exist provide for the most rapid, well controlled, small boat surveys possible. Any set of tangents, offsets and fillets may be specified making the system useful as an aid in the performance of surveys in any navigable waterways.

#### ACKNOWLEDGEMENTS

The author wishes to thank GOULD Inc. and Science Applications, Inc. for their mutual cooperation in making the presentation of this paper possible.

Recognition should also go to Juris Jurisons of the Portland district, U.S. Corps of Engineers for his excellent feedback of operational information and data pertaining to the systems described.

PERFORMANCE EVALUATION OF  
SURVEYBOAT RODOLF

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BIOGRAPHICAL SKETCH

David H. Sims received a BS degree in Mechanical Engineering from Oregon State University. Since his graduation in 1955, he has been with the Army Corps of Engineers. Mr. Sims has worked in the Navigation Division of the Portland District for 22 years. Sixteen years were spent in the Plant Branch, involved with the operation and maintenance of floating plant. During the past 6 years he has been the Chief, Technical Services Branch and has directed the District Hydrographic Survey effort. His Branch had the responsibility for selection, procurement and operation of the SES Surveyboat RODOLF. He is a member of SAME and a registered Professional Engineer in the State of Oregon.

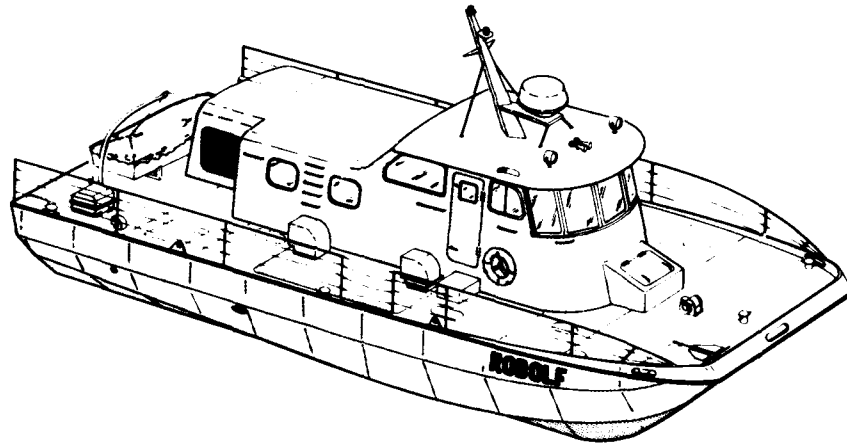
ABSTRACT

The surveyboat RODOLF is the result of the Portland District's efforts to select, acquire, and operate a high-speed survey boat. The RODOLF is an example of surface-effect-ship (SES) technology; the concept of an air-cushion supported vessel with rigid side hulls. With air-cushion assist, up to 80% of the vessel weight is supported by air pressure. Approximately one year of operating experience has been accumulated with the RODOLF in the Portland District. The Air-cushion assist principle has proven itself to be a fuel efficient method of attaining high performance with reduced propulsion power requirements. Survey speeds of 25 mph are attainable with the RODOLF. Handling and maneuvering characteristics are similar to regular planing hulls in many ways. Turning and maneuvering at higher speeds are readily accomplished in a manner much like a planing monohull. However, operation of the vessel on one engine is not practical because of the wide spacing of engines, and rudders offset from propellers, causing the vessel to continually turn in one direction. Sea keeping characteristics deteriorate rapidly when operating into seas with wave heights greater than 6 feet, depending on the type of wave form. When operating in a following sea, the RODOLF operates exceedingly well. Ocean operations are severely limited and only considered during periods of fair weather.

BACKGROUND

On November 22, 1978, a contract was awarded to Bell-Halter (a joint venture of Bell Aerospace and Halter Marine, Inc.) New Orleans, Louisiana, to build a 48 foot surface effect ship for the Portland District, as a prototype high-speed surveyboat. The vessel was completed in December 1979, and delivered to the Portland District in New Orleans. After completion of a demonstration tour between New Orleans and Washington, DC, the RODOLF arrived at the Columbia River, Oregon in September 1980, as deck cargo on a Military Sealift Command Ship.

The RODOLF has been in service in the Portland District more than one year. The capability to survey at a speed of 25 miles per hour has been confirmed. Activities have included surveying and mobilizing operations under various conditions. Many problems have occurred during this period of operation, including equipment repairs, modifications and alterations to improve performance. The RODOLF has replaced the Surveyboat NORMAN BRAY and is currently being utilized on a regular basis performing hydrographic survey work on the Columbia and Lower Willamette Rivers between Portland and Astoria (105 miles).



#### OFF-CUSHION OPERATION

Off-cushion operation is similar to that of a displacement or semi-planing catamaran. At slow speeds the hull operates in a displacement mode like a planing vessel would. Sufficient propeller thrust is available to push the vessel well beyond the displacement hull speed into a semi-planing mode of operation at 15 mph. However, continuous off-cushion operation is not desirable, except at low speed, as damage can occur to the stern seal because it fills with water when not pressurized. At low speed the rudders have minimal effect on directional control. Low speed maneuvering is primarily a function of differential propulsion engine power settings. As hull speed increases, the rudders begin to contribute more to steering control.

#### ON-CUSHION OPERATION

On-cushion slow speed maneuvering and directional control is primarily accomplished by differential propulsion engine power settings just as in the off-cushion mode. Directional control above 15 miles per hour can be accomplished with rudders only.

The RODOLF can readily attain speeds of 35 miles per hour. The maximum speed attained has been 38 miles per hour, which was achieved in calm water conditions with minimum payload aboard. Propulsion and lift engine power output to achieve these speeds are within the engine manufacturers continuous crew boat power rating, not some short duration maximum output rating. Operating the propulsion and lift engines at approximately 1900 rpm permits the RODOLF to comfortably cruise at approximately 30 miles per hour.

#### SINGLE ENGINE OPERATION

Single engine operation is not practical. If only one propulsion engine is available, the unbalanced thrust causes the vessel to continually turn in one direction despite full rudder in the opposite direction. This has an adverse impact on operational considerations and vessel capability. Vessel and crew safety could be compromised under adverse sea conditions because of the inability to maneuver safely.

This problem is caused by two factors. The wide spacing of the engines, and the rudders being offset approximately 11 inches from the propeller centerlines. Structural alterations required to relocate the rudders in line with the propellers are difficult and involve considerable work. For this reason the modification has not been undertaken.

Another method to improve steering capability includes installing a portable rudder directly behind the available propulsion unit during single engine operation. This should improve steering capabilities and will be tested in the near future.

#### WAKE

Wake generated during slow speed off-cushion operation is comparable to a planing hull operating in the displacement mode. As speed increases, displacement operation is less efficient and wake increases. During the on-cushion, semi-planing transition condition between displacement and planing modes of operation a large bow wave is formed. The condition is worse between 10 and 20 miles per hour, depending upon the amount of cushion pressure applied. High-speed operation again produces a minimal wake.

#### OCEAN OPERATION

West Coast ocean operation has been undertaken several times with results that have been less than satisfactory because of rough sea conditions. However, a trip was completed across the Gulf of Mexico from Panama City, Florida to Tampa, Florida (220 miles) at a low sea state. Ride quality into a head sea with wave heights above 6 feet rapidly deteriorates with increasing sea state, and handling and maneuverability become very cumbersome even at reduced speeds. As wave conditions increase, vertical acceleration of the vessel increases rapidly to the point of discomfort for personnel aboard.

When operating in a following sea, response is quite different. The combination of relative speed between the vessel and wave, and the slope of the wave fronts improves the vessel ride considerably. Under following sea conditions the ride quality improves much more dramatically than would be expected compared to its inability to operate in head seas.



## AIR-CUSHION SUPPORT SYSTEM

The air-cushion support system consists of a diesel engine, a double inlet centrifugal fan, air distribution ducts that are integral with the hull structure, and bow and stern flexible seal assemblies. The seal assemblies are fabricated from neoprene coated, woven nylon fabric that was specifically engineered for SES applications (See Figure 1). The bow seal consists of six segments. Wear occurs on the lower edge of the bow seal segments, which are in contact with the water. These lower edges tend to vibrate rapidly, eventually cracking and separating the neoprene coating from the nylon fabric. As the process of separation and fabric deterioration continues, the edge progressively wears away exposing new material to continue the wear cycle.

Results of inspections on the bow seal indicates that the rate of wear accelerates with time (See Figure 2). The service life of the bow seal now appears to be considerably less than initial wear rates had predicted. After approximately 7 inches of wear on the bow seal, the segments have to be removed and the lower portion replaced. Segment repair is still in the experimental phase and will be accomplished by vulcanizing, mechanical fasteners or both.

A worn set of bow seals have just been repaired with hired labor forces. Semi-circular pieces were cut from the worn seal segments, removing the worn area. New pieces were cut from a roll of the same material, allowing a 3 inch overlap. The new pieces were glued to the seal segments and secured with two rows of  $\frac{1}{4}$  inch pop rivets set on 4 inch centers. The rebuilt segments were installed, and additional wear rates will be monitored to determine the effectiveness of the repairs. New bow seal segments of heavier material will be installed in the near future and should extend the life of the seal.

Stern seal wear has not presented any special problems. The design of the stern seal consists of an inflatable bag assembly attached to the cross structure of the hull. The end panels of the inflated stern seal press against the side hulls and the bottom surface inflates against the water surface to contain the air. This design does not expose any edge which can vibrate and wear. The only significant wear observed has been on the end-panels of the seal, which rub against the side hulls.

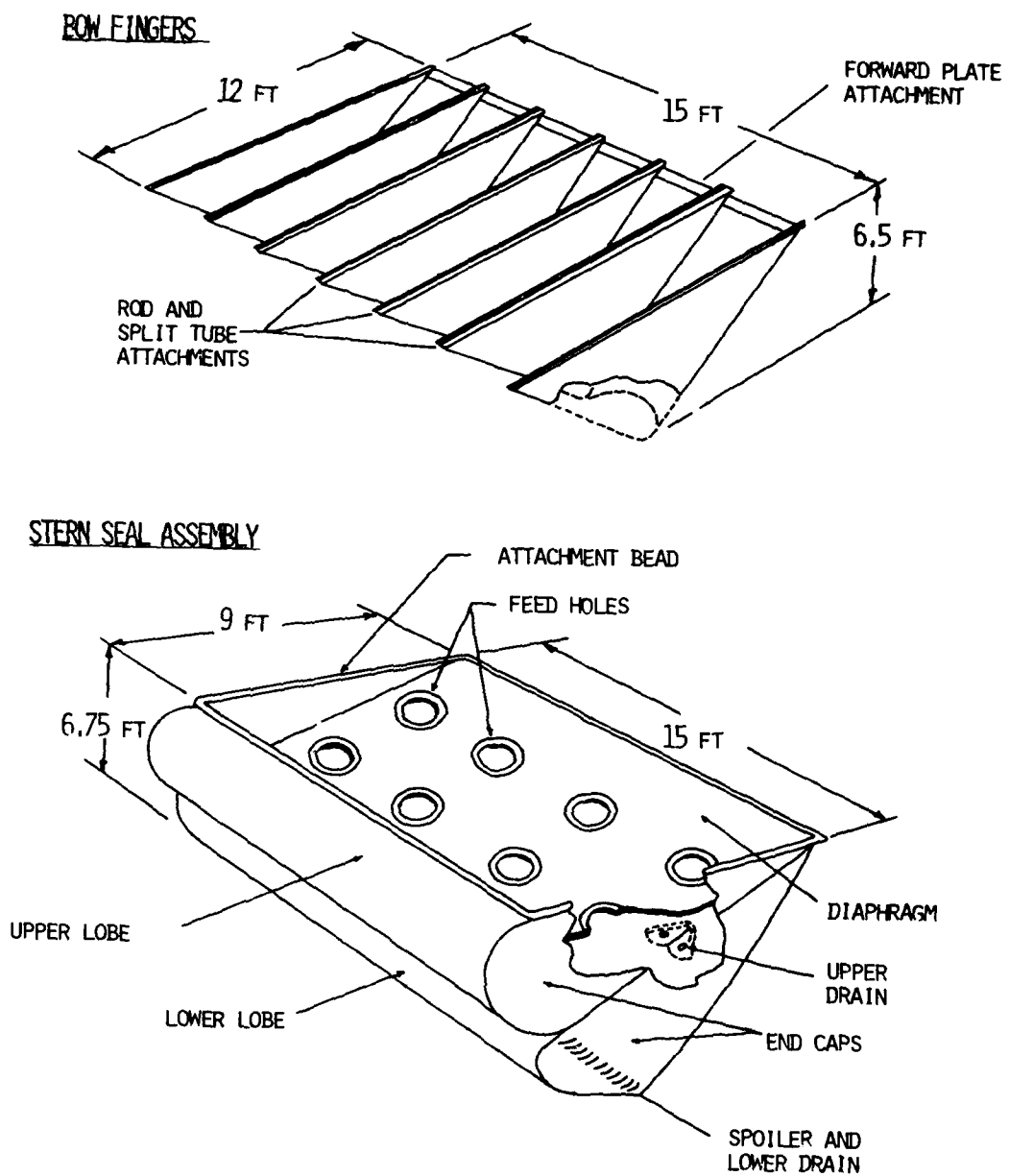


FIGURE 1. BOW AND STERN SEALS

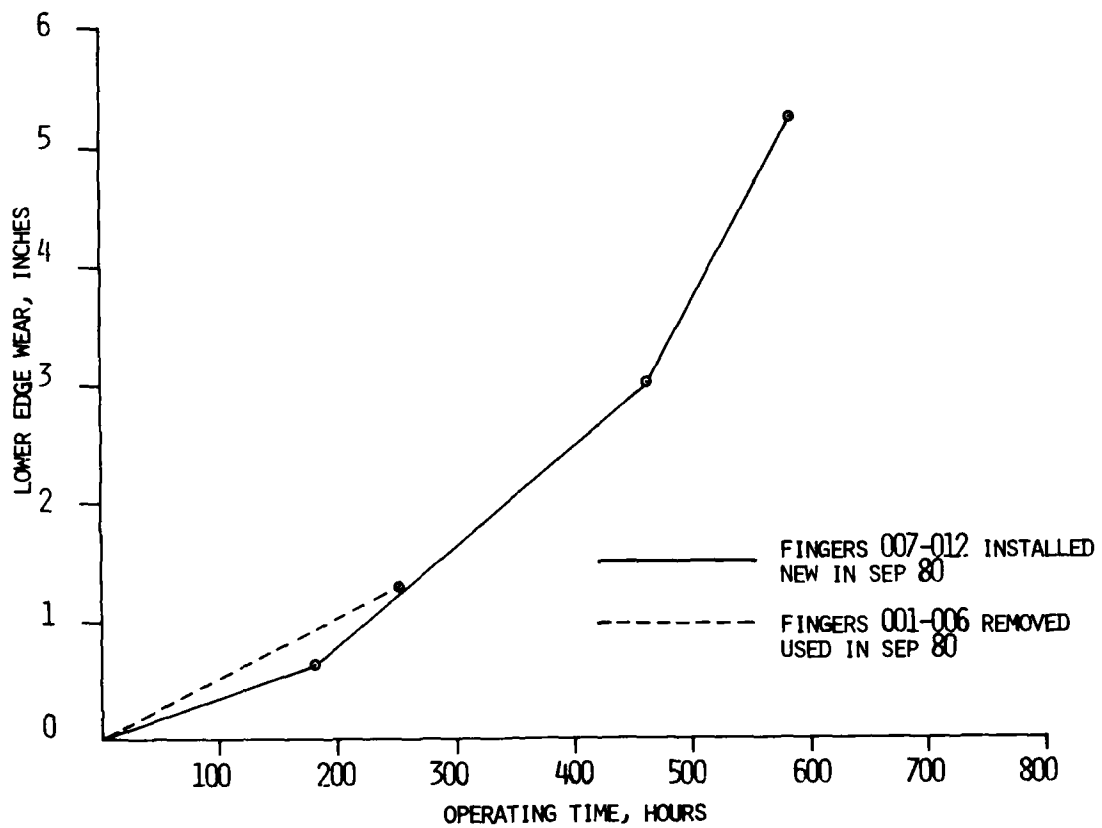


FIGURE 2. BOW SEAL FINGER WEAR

## SURVEY SYSTEM

The integrated Hydrographic Survey System used on our surveyboat RODOLF is a Decca-designed Custom Auto-Carta system and is operated by a three person survey crew. Inputs from the Del-Norte Electronic Positioning System, and Ross Fine Line Depth Sonar are stored in the computer memory and are transcribed onto a magnetic tape. The system includes a Houston Instrument Model DP-3 Plotter, with all equipment interfaced to the computer.

The system utilizes a "2-Pass" technique. Data accumulated and track plotting will be accomplished in an on-line surveying mode. Data outputs, chart plotting, quantity computations, etc., are provided in an off-line editing mode. During the surveying process (on-line mode), data from the electronic positioning system and depth sonar is being accumulated and stored on a magnetic tape. In addition, a track plot is being made of the vessel's movement during the entire survey. During the off-line editing mode, soundings will be edited, processed and plotted with the on-board plotter; and simultaneously, edited data will be transcribed to a second magnetic tape. The edited tape is sent into the District Office, where final plotting of the chart is completed on a computer actuated flatbed plotter.

Depth correction for tide or river level is made during the editing phase after inserting the proper correction into the computer. When editing the raw depth data, the correction is added (or subtracted) to the raw depth, and the corrected depth is produced on the edited tape.

Correction for height of the vessel when on-cushion is put into the depth sonar and corrected depths are recorded during the survey run. This height correction is checked before each survey, by putting the surveyboat on-cushion and performing a bar check; noting the correction factor and setting this factor into the depth sonar. All surveys are completed using the same lift fan speed; giving the same cushion pressure and height above the water surface.

## CONCLUSION

The project objective of acquiring and testing a prototype high-speed Surface Effect Ship as a surveyboat has been successfully accomplished. The RODOLF is being utilized on a daily basis as a surveyboat contributing to Portland District's hydrographic survey mission. This project has demonstrated that higher speed surveys are practical and can be accomplished by vessels of this size. Although the RODOLF has demonstrated capabilities in several important areas, and because it is a prototype model, numerous equipment and operational problems have also been encountered.

An SES is a valid method of attaining high speed performance at reduced power requirements when compared to a conventional planing monohull. Fuel consumption of the RODOLF compares favorably with slower speed vessels of similar size. The first years cost of operation has been higher than expected due to required modifications, equipment repairs and higher than expected repair factor on the bow seal; resulting in excessive loss of production time. Those costs should decrease in the future to make this vessel more cost effective and competitive with our existing surveyboats.

## TECHNICAL DATA

### DETAILS OF BOAT

LENGTH . . . . . 48 FEET  
BEAM . . . . . 24 FEET  
DEPTH, MOLDED . . . . . 7 FEET, 1 INCH  
MAX DRAFT . . . . . 5 FEET, 10 INCHES  
(OFF CUSHION)  
MAX DRAFT . . . . . 4 FEET  
(ON CUSHION)  
DISPLACEMENT . . . . . 55,000 POUNDS  
(FULL LOAD)  
FUEL CAPACITY . . . . . 1,400 GALLONS  
RANGE. . . . . 1,000 STATUTE MILES

### MACHINERY

PROPULSION. . . . Two 8V-92N DETROIT DIESEL MARINE  
ENGINES, 350 SHP EACH  
TWO 24-INCH-DIAMETER, FOURBLADED  
STAINLESS STEEL PROPELLERS  
LIFT. . . . . ONE 4-53N DETROIT DIESEL MARINE  
ENGINE, 105 SHP  
ONE BELL 30-INCH-DIAMETER CENTRI-  
FUGAL FAN  
GENERATORS. . . . Two ONAN, 7.5 KW EACH

### SURVEY ELECTRONICS

DECCA SURVEY SYSTEMS, INC. INTEGRATED ELECTRONIC  
SURVEYING SYSTEM

- DEL NORTE TRISPONDER ELECTRONIC POSITIONING
- ROSS LABORATORIES DIGITIZING FATHOMETER
- HOUSTON INSTRUMENTS X-Y PLOTTER
- DIGITAL EQUIPMENT COMPUTER AND TERMINAL
- DIGITAL EQUIPMENT MAGNETIC AND PUNCH TAPES
- DECCA SURVEY INTERFACES, SOFTWARE, AND LEFT/RIGHT INDICATORS

# A SIMPLIFIED PROCEDURE FOR FIELD CALIBRATION OF ELECTRONIC LINE-OF-SIGHT POSITIONING SYSTEMS

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## BIOGRAPHICAL SKETCH

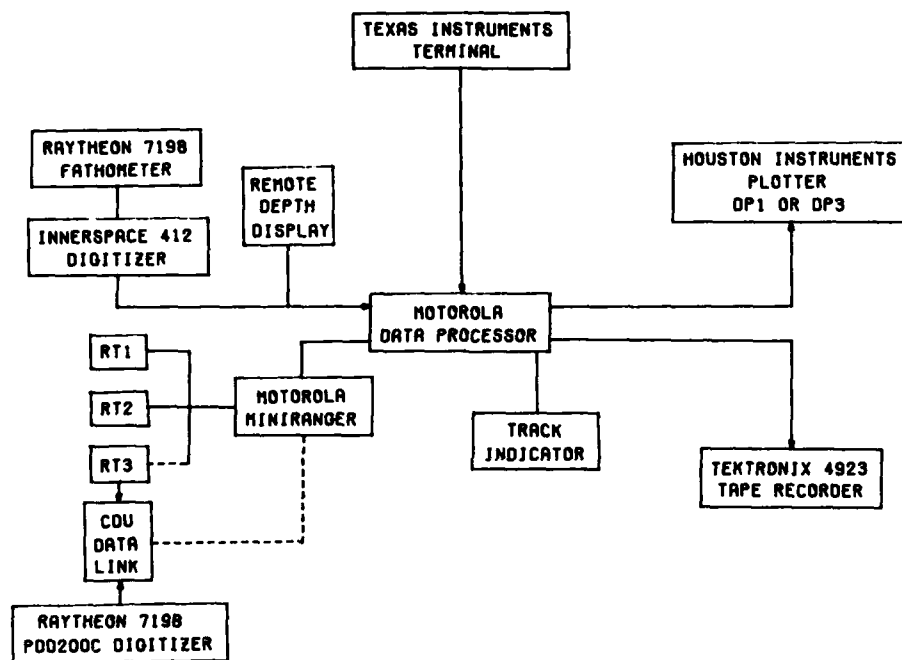
Charles G. Boone is an oceanography graduate of Old Dominion University, Norfolk, Virginia, where B.S. and M.S. degrees were received in 1966 and 1971, respectively. Following graduation he served with the Norfolk District, Corps of Engineers and the U.S. Army Waterways Experiment Station, Vicksburg, Mississippi. He currently is Chief, Survey Section, Wilmington District, Corps of Engineers. Mr. Boone is Vice-President, South Atlantic States Unit, committee on Marine Surveying and Mapping, ACSM.

## ABSTRACT

An evaluation of a procedure to calibrate microwave line-of-sight range positioning equipment is presented. The mean range errors observed varied between  $\pm 15$  feet for the eight transponders tested. Temporal variations in range errors were accounted for using these procedures. Analysis of the data obtained suggest that calibration plots for each transponder can be developed and used on a daily basis to simplify the range calibration process. Adoption of this calibration procedure is expected to facilitate the daily calibration of microwave hydrographic survey equipment with no adverse effect on operational precision.

## INTRODUCTION

The Wilmington District currently utilizes three Motorola hydrographic survey systems for the conduct of routine condition and dredging surveys. Two of these systems have been in operation for approximately 4 years, while the third system has been in use since 1980. With minor exceptions, each system is identically configured, as shown in Figure 1. The data acquisition and procession aspects of these systems were discussed by McCoy (1978). It has been standard practice to calibrate these systems each day prior to conducting the assigned survey. This calibration procedure involves observing the incoming range data on the range console or data terminal and comparing it with known range data. This calibration procedure often takes as much as 1 hour to complete, and for this reason some alternate calibration is desired. During the calibration process, a daily calibration log is tabulated for each transponder showing the calibration distance, the receiver-transmitter balance, and the before and after the calibration ranges. Examination of these calibration logs provides the basis for this paper.



INTEGRATED AUTOMATED SURVEY SYSTEM  
WILMINGTON DISTRICT  
JANUARY 1982

Figure 1. Diagram of component parts of Wilmington District Survey System

## CALIBRATION PROCEDURE

The Motorola Mini-Ranger III system used on Wilmington District survey vessels is a line of sight C-band microwave positioning system which operates between 5475 and 5625 MHz. One of the options in this system is space diversity which, in effect, eliminates loss of incoming range data in range holes due to phase cancelation when direct path signal and reflected path signal arrive simultaneously at the receiver 180 degree out of phase. Space diversity requires two receiver transmitters (RT) on the mobile vessel, generally separated by 10 to 12 feet in the vertical plane. Vessel positioning using this equipment is based upon the elapsed time between the transmitted pulse on the mobile vessel and the reference station reply pulses. The onboard Motorola processor assimilates the range data between the vessel and the fixed reference stations and the known position of the reference stations. Subsequently, using trilateration, the processor computes the position of the vessel.

Normal daily calibration of the ranging equipment necessitates that the survey vessel be tied up at a fixed known location where the coordinates of the receiver-transmitter mast on the vessel have been computed. Two or more reference stations are then installed at known points. The distance between the reference stations and the RT's on the vessel provides the calibration distance. As a general rule, this distance is determined by inverting between the coordinates of the known points and rounding the value to the nearest whole foot. The Mini-Ranger is then powered up and the appropriate codes are selected and allowed to warmup for a period of approximately 15 minutes. Following the warmup period, which is slightly dependent upon the ambient air temperature, the incoming range information is compared with the calibration range. This comparison is made through the data processor in a calibration mode where the respective range information is output to the data terminal. Range values for one transponder code are individually evaluated on each R/T by switch selection on the A6 space diversity board in the range console. The timing of each incoming signal on RT 1 and RT 2 is then adjusted on variable resistors R15 and R16 to balance the RT's in the same vertical plane, irrespective of whether or not the range valves are absolutely correct. Once the R/T's are balanced on a given reference station, the space diversity switch on the A6 board is then switched to the auto position for the remainder of the calibration procedure. In the auto position, the incoming range from the R/T having the greatest video amplitude is passed on through the range console to the processor. The remainder of the calibration process involves determination of the sign and magnitude of the range error or errors, if two different calibration distances are used. Following this determination, the appropriate range correction may either be mechanically adjusted through the calibration potentiometers on the range console or they may be entered into the data processor in the data entry mode through software. Identical results are obtained from either method; however, the mechanical adjustment is slightly preferred since the required range correction is not lost in the event of power loss to the system.



# CALIBRATION RESULTS AND DISCUSSION

The daily calibration logs for the survey vessels GILLETTE and WANCHESE have been analyzed for a 3-year period beginning in 1979. These data have been reduced and are summarized in Table 1. Figures 2-9 display the calibration distance - range correction relationships for four transponder codes for each vessel. These data are plotted using a least-squares polynomial regression program which fits a polynomial curve of a specified degree to the data set. The equations printed on the figures represent the least squares fit for a linear, quadratic, and cubic relationship between the two variables.

Table 1  
Summary of Transponder Calibration Data  
for Two Survey Vessels

Survey Vessel	Transponder Code	N	Mean Range Correction	Standard Deviation	Coefficient of Linear Correlation
GILLETTE	1	143	-0.89	7.92	-0.30
GILLETTE	2	28	1.5	8.95	0.28
GILLETTE	3	112	-1.03	7.98	-0.56
GILLETTE	4	74	2.13	8.50	-0.23
WANCHESE	1	229	-0.86	6.30	-0.20
WANCHESE	2	48	1.0	7.86	0.02
WANCHESE	3	184	0.16	7.07	-0.06
WANCHESE	4	111	-0.17	7.90	-0.05

Examination of the GILLETTE data for the four transponder codes indicate that similar trends appear for codes 1, 3, and 4, since these codes were used considerably more often than code 2. The majority of the range correction values for codes 1, 3, and 4 were found to vary between  $\pm 15$  feet, with the greatest variations occurring with calibration distances of less than 15,000 feet. Range errors also had a greater tendency to be negative, as the observed range was greater than the calibration or expected range. The linear correlation coefficients for these three transponder codes were all negative and exhibited only a moderate amount of linear statistical relationship between the independent and dependent variables. The relationship which exists between the two variables for these three codes is probably best explained by a quadratic or cubic curve and equation. Data observed from GILLETTE code 2 appear to be more erratic, and do not exhibit any linear or curvilinear relationships. An insufficient number of observations for this code precludes much statistical inference.

The data derived from calibration logs on the WANCHESE have been examined and are also summarized in Table 1. Similar trends are observed in this data set. The variation in the dependent variable (range correction) was found to be nearly identical to the GILLETTE, with greatest majority of the values falling between  $\pm 15$  feet. A similar trend was

# GILLETTE CALIBRATION CURVE CODE 1 (1979-1981)

$$Z = X - 7.6637$$

$$\bullet Y = -0.07801Z - 0.8951$$

$$\bullet Y = -0.01322Z^2 + 0.1355Z - 0.1508$$

$$\bullet Y = +3.2305(10^{-3})Z^3 - 0.09531Z^2 + 0.05486Z + 1.5621$$

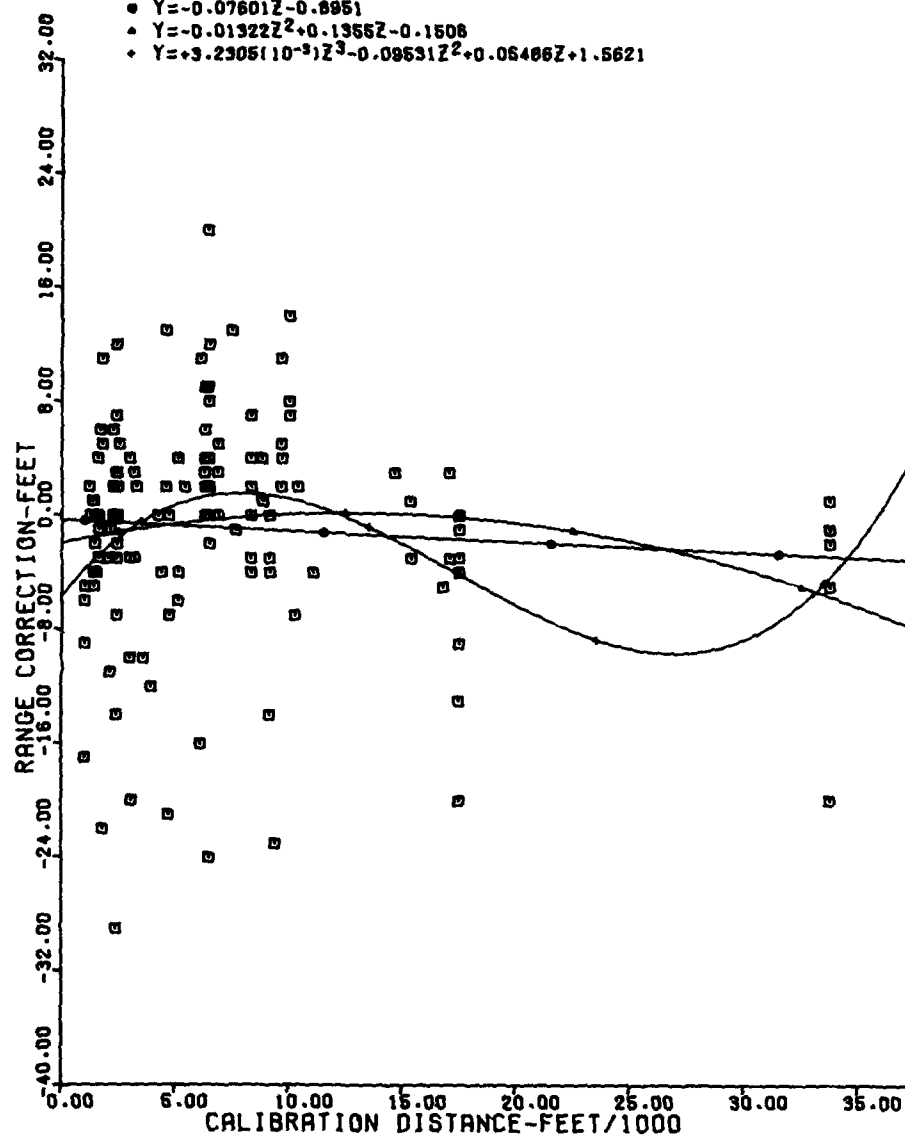


Figure 2. Calibration Plot GILLETTE Transponder Code 1.

# GILLETTE CALIBRATION CURVE CODE 2 (1979-1981)

$$Z = X - 6.6106$$

$$Y = +0.6602Z + 1.5000$$

$$Y = -0.00184Z^2 + 0.9534Z + 2.6789$$

$$Y = -4.5896(10^{-3})Z^3 - 0.05534Z^2 + 1.0972Z + 2.5339$$

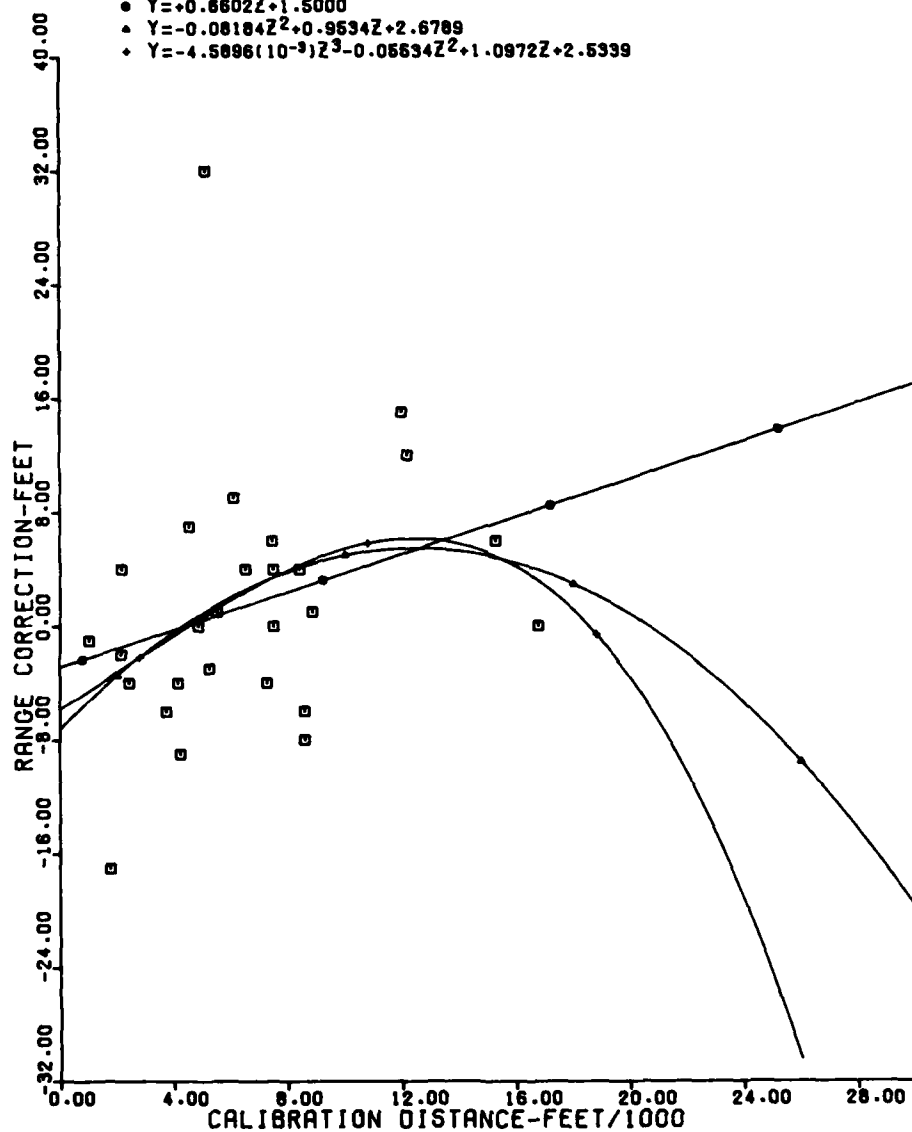


Figure 3. Calibration Plot GILLETTE Transponder Code 2.

# GILLETTE CALIBRATION CURVE CODE 3 (1979-1981)

$$Z = X - 5.6559$$

$$\bullet Y = -0.4337Z - 1.0357$$

$$\blacktriangle Y = -0.01720Z^2 - 0.2355Z - 0.6315$$

$$\blacklozenge Y = +3.7475(10^{-3})Z^3 - 0.1241Z^2 - 0.07300Z + 0.8661$$

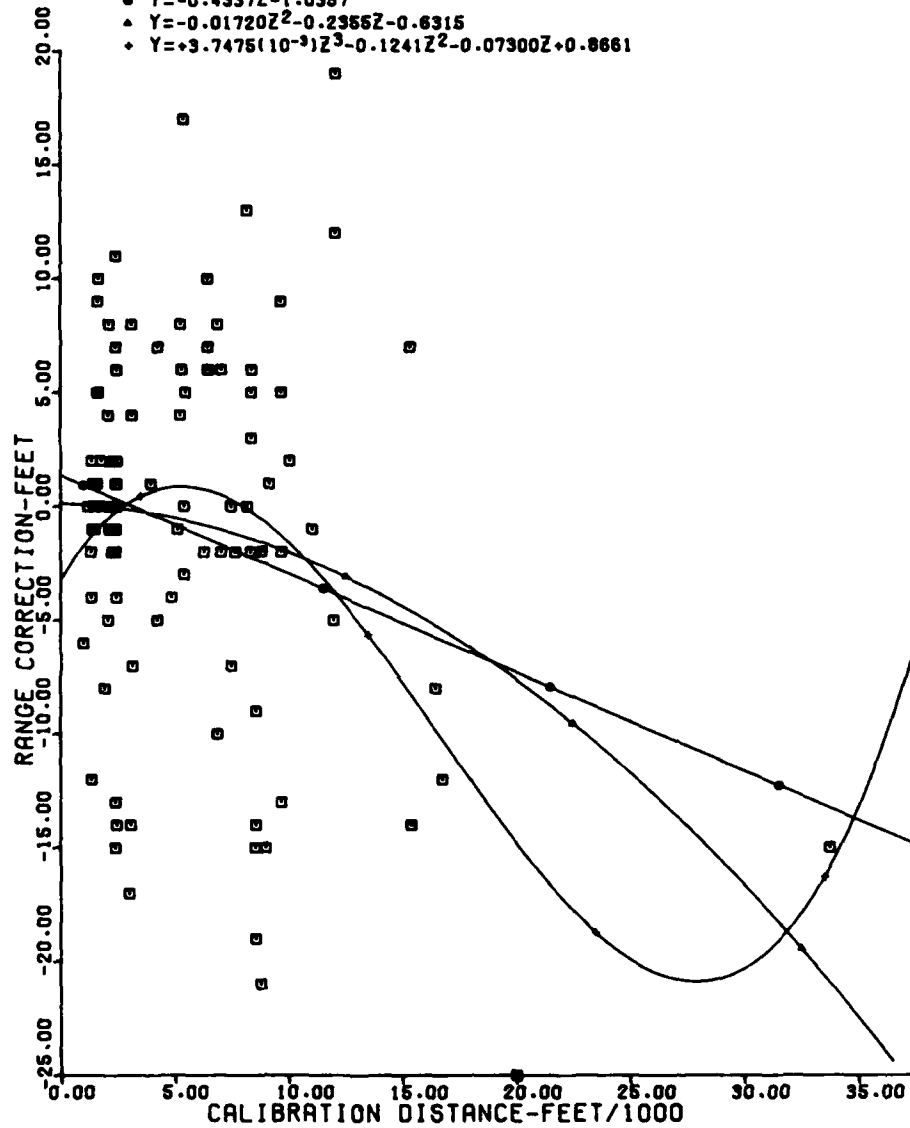


Figure 4. Calibration Plot GILLETTE Transponder Code 3.

# GILLETTE CALIBRATION CURVE CODE 4 (1979-1981)

$$Z = X - 0.0625$$

$$\bullet Y = -0.2063Z + 2.1351$$

$$\blacktriangle Y = -7.4490(10^{-3})Z^2 - 0.1429Z + 2.4743$$

$$\blacklozenge Y = -1.8846(10^{-3})Z^3 + 0.03313Z^2 + 0.06106Z + 2.2798$$

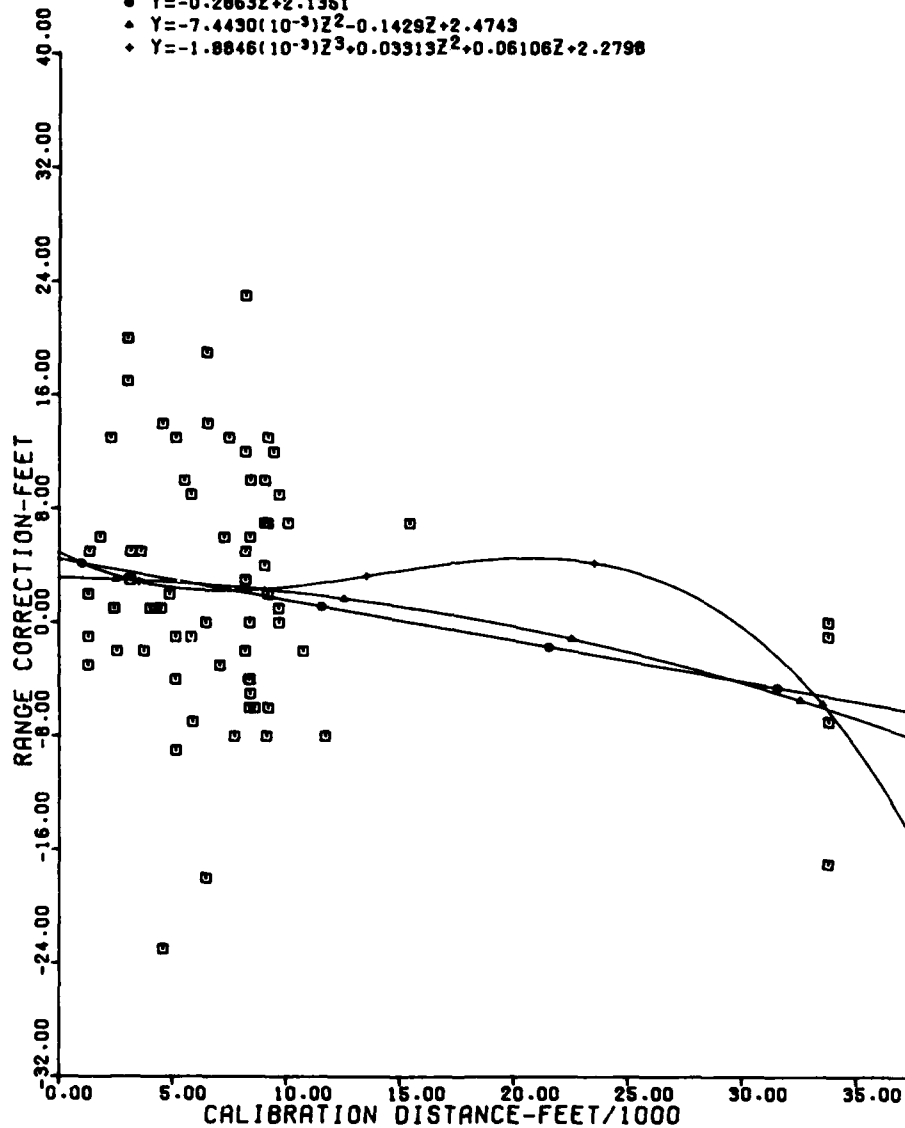


Figure 5. Calibration Plot GILLETTE Transponder Code 4.

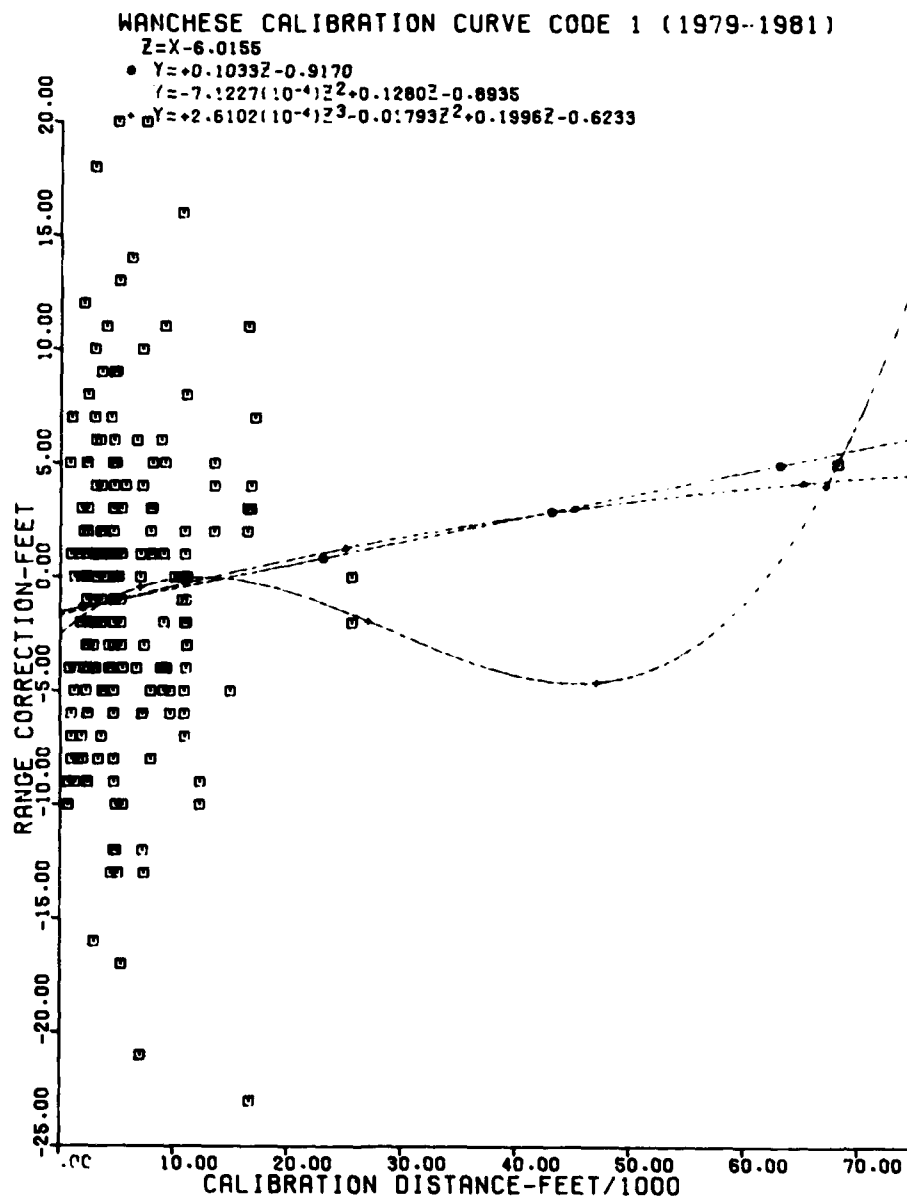


Figure 6. Calibration Plot WANCHESE Transponder Code 1.

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U.S. ARMY CORPS OF ENGINEERS SURVEYING REQUIREMENTS MEETING, 2---ETC(U)  
APR 82 E D HART, G C DOWNING

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# WANCHESE CALIBRATION CURVE CODE 2 (1979-1981)

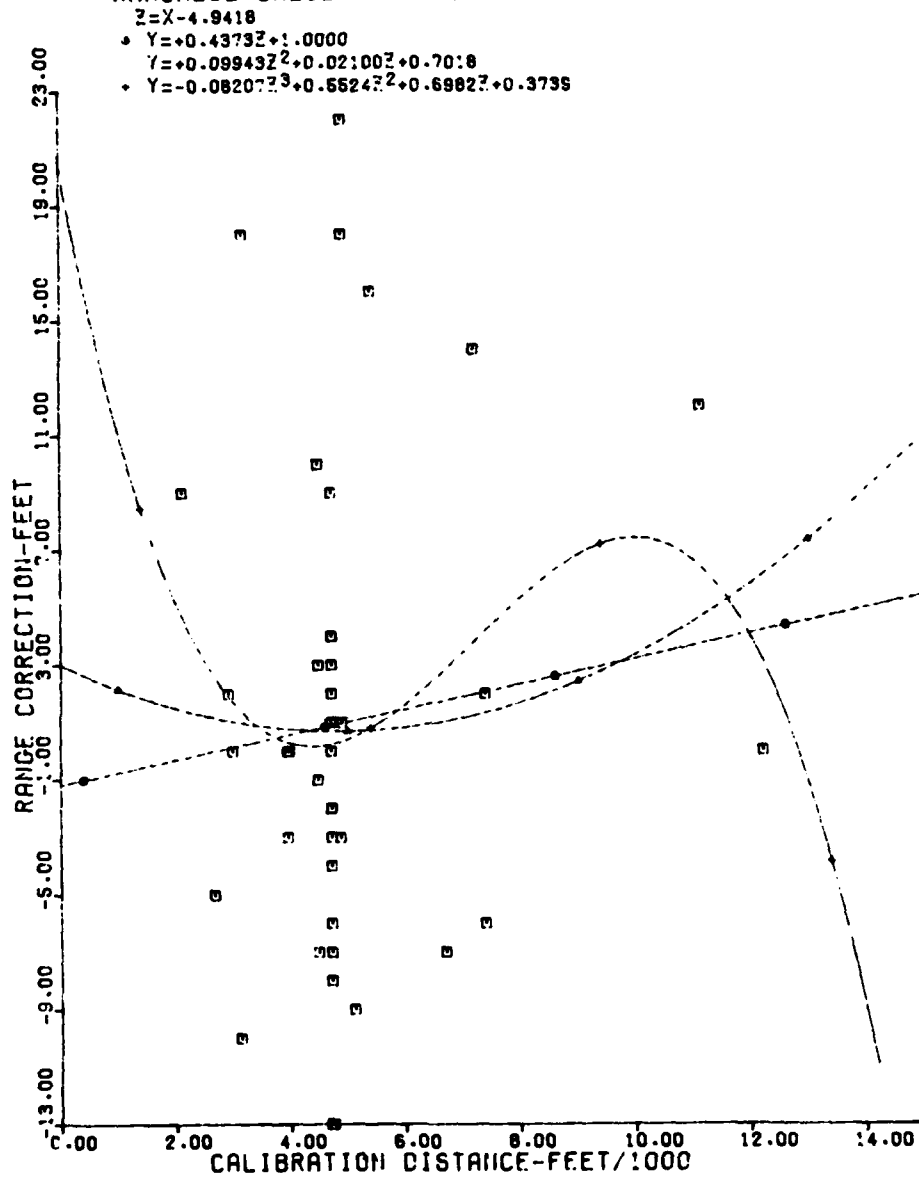


Figure 7. Calibration Plot WANCHESE Transponder Code 2.



# WANCHESE CALIBRATION CURVE CODE 3 (1979-1981)

$$Z = X - 6.7809$$

$$\bullet Y = -0.08141Z + 0.1250$$

$$\bullet Y = -0.05719Z^2 + 0.3006Z + 1.6466$$

$$\bullet Y = +2.3301(10^{-3})Z^3 - 0.07894Z^2 + 0.2214Z + 1.8114$$

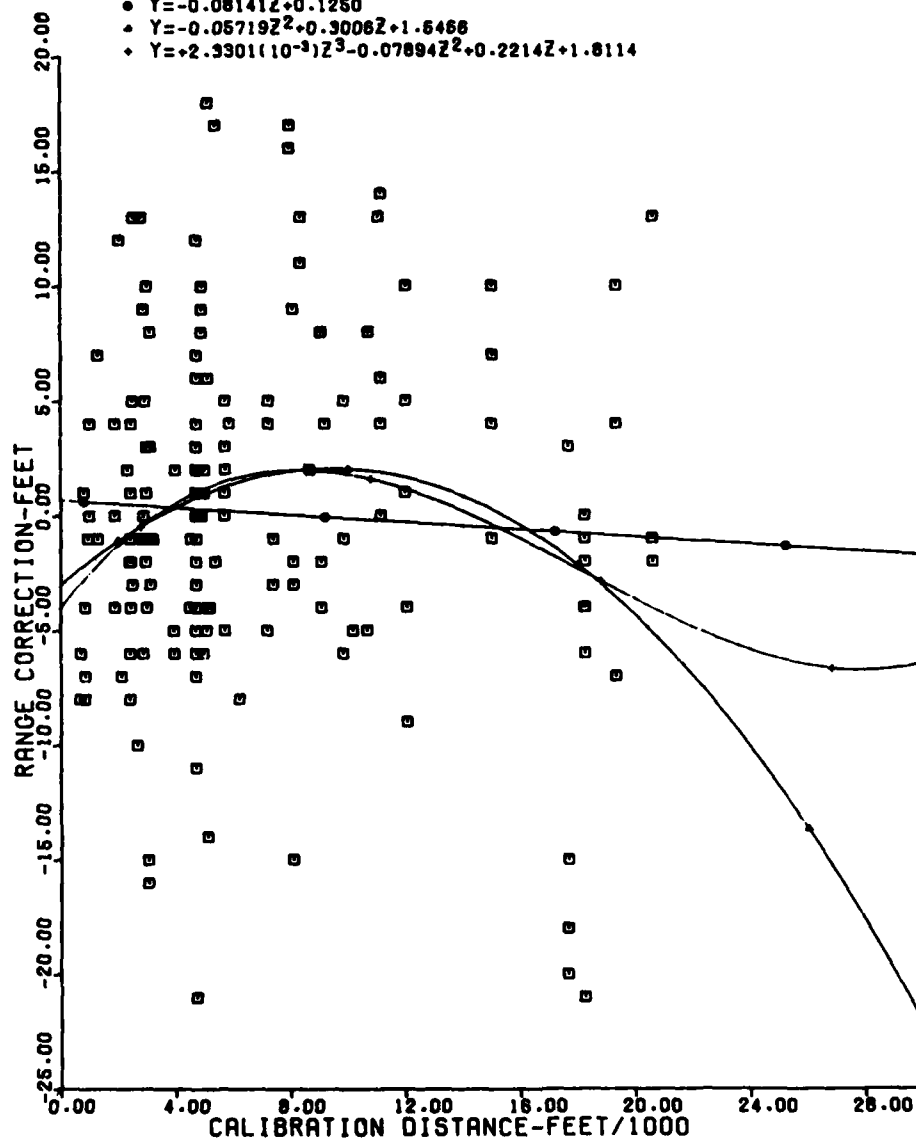


Figure 8. Calibration Plot WANCHESE Transponder Code 3.

WANCHESE CALIBRATION CURVE CODE 4 (1979-1981)

$$Z = X - 5.7854$$

$$\bullet Y = +0.02766Z - 0.1712$$

$$\blacktriangle Y = -5.4572(10^{-3})Z^2 + 0.08227Z - 0.07867$$

$$\blacklozenge Y = +1.5418(10^{-3})Z^3 - 0.03430Z^2 + 0.07567Z + 0.1487$$

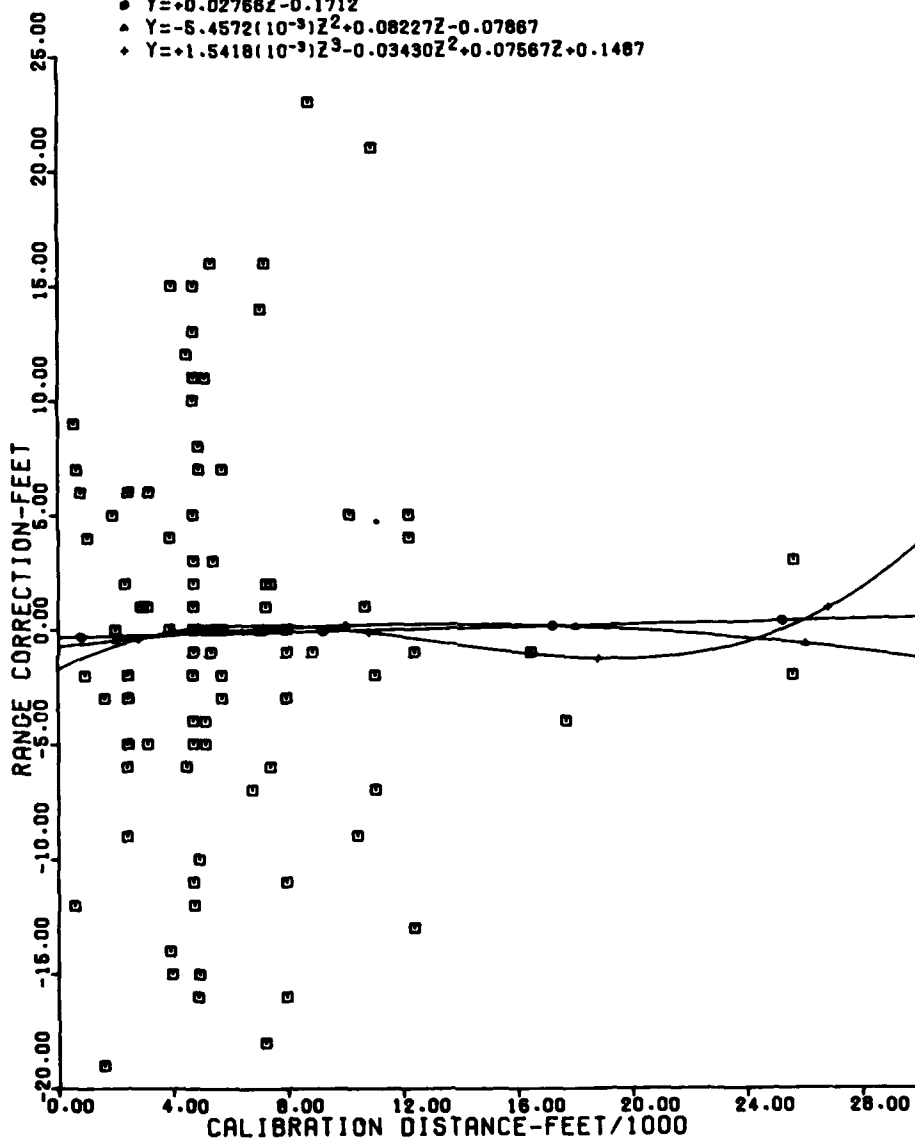


Figure 9. Calibration Plot WANCHESE Transponder Code 4.

observed with the variability of the range errors in the shorter calibration distances with all codes except code 3. Range correction variation with this code appeared to be independent of the calibration, despite the fact that it was one of the most frequently used transponders.

Examination of the linear correlation coefficients for this set of data also supports the idea that there is no apparent linear correlation between the variables and that some form of higher order curve best describes the variability in the data sets. Transponder code 1 was the only reference station which exhibited a slight negative linear correlation. Since none of the reference stations exhibited any significant linear correlation, the linear least squares fit equation cannot be used to accurately predict the value of the dependent variable (range correction) from a known X value.

Review of the calibration curves plotted for each survey system suggests that the third degree polynomial provides the best least squares fit of the data groups. The equations for these curves can be used to estimate a value for the appropriate range correction given an average operating range. This estimated range correction value is based on the observed data for each transponder code for a 3-year period, and with few exceptions, is believed to be accurate. Notable exceptions were found with GILLETTE and WANCHESE code 2, figures 3 and 7, respectively, as insufficient data were available for accurate predictions. The following equations may be used to estimate the appropriate range correction, with a known survey range.

GILLETTE Code 1  $Y = 0.00323(X-7.55)^3 - 0.095(X-7.55)^2 + 0.054(X-7.55) + 1.56$   
 GILLETTE Code 3  $Y = 0.00374(X-5.55)^3 - 0.12(X-5.55)^2 - 0.073(X-5.55) + 0.86$   
 GILLETTE Code 4  $Y = -0.0018(X-8.06)^3 + 0.033(X-8.06)^2 + 0.061(X-8.06) + 2.28$   
 WANCHESE Code 1  $Y = 0.00026(X-6.02)^3 - 0.018(X-6.02)^2 + 0.199(X-6.02) - 0.62$   
 WANCHESE Code 3  $Y = 0.0023(X-6.78)^3 - 0.08(X-6.78)^2 + 0.22(X-6.78) + 1.81$   
 WANCHESE Code 4  $Y = 0.0015(X-5.76)^3 - 0.34(X-5.76)^2 + 0.075(X-5.76) + 0.15$

It should be noted that the calibration distances have been divided by a factor of 1,000 in order for the curve plotting program to accept the numbers. As a result, the equation  $Z = X -$  the average value of the X array also reflects this division factor. The equations may be used directly to estimate the Y value if the average survey range is also divided by this same factor.

#### SUMMARY AND CONCLUSIONS

A group of calibration data collected in the field over a 3-year period have been tabulated, analyzed, and summarized. Results of this exercise suggest that the measured calibration data and range corrections may be useful in estimating a particular range correction for a given transponder code knowing the approximate range to be encountered in the survey area. Application of these results to actual field calibration procedures will expedite the calibration process without adversely affecting the

operational accuracy of the survey system. Periodic calibration checks will, however, be necessary to verify this suggested calibration procedure and also to check on the condition of the transponders.

#### ACKNOWLEDGEMENTS

The author would like to express his thanks to Mr. O. J. McCoy who was instrumental in adapting the software used to process and plot the data and to Ms. Benjamin and Ms. Hayes of the Survey Section who prepared the data for computer processing.

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## SURF ZONE AND NEARSHORE SURVEYING WITH THE CRAB AND A TOTAL STATION

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### BIOGRAPHICAL SKETCH

William A. Birkemeier is a Hydraulic Engineer with the Coastal Engineering Research Center (CERC). He received a BS in Physics from Worcester Polytechnic Institute and a MS in Civil Engineering from the University of Delaware. Since joining CERC in 1975, his main research interests include the effects of storms on beaches, bluff recession in the Great Lakes, and the problems associated with collecting and analyzing accurate beach survey data. He is presently working at CERC's Field Research Facility located in Duck, North Carolina.

### ABSTRACT

Accurate surveying of the ocean bottom is a difficult yet important task for determining changes in the nearshore zone. A recent innovation in obtaining this type of data involves combining a Zeiss Elta-2 electronic total station with the Coastal Research Amphibious Buggy (CRAB), a specially built three-wheel vehicle which is able to move from the beach, through the high-energy surf zone, out to a depth of 30 ft. Top speed of the CRAB is 2 miles per hour, and it can operate in waves up to 6 ft in height. During use, the operator of the total station is required only to aim the instrument at a prism cluster mounted on the CRAB; the instrument automatically computes and records the X, Y, and Z coordinates of the point under the CRAB. When the survey is completed, the data are transferred directly to a computer for further analysis and plotting. Because of this, instrument reading and transcription errors are virtually eliminated. A typical 3,500-ft-long profile can be surveyed in about 45 minutes and 1 day's survey can be reduced and plotted in 1 hour or less. In addition to surveying, the CRAB can also be outfitted to perform various other tasks in the surf zone, such as taking sand samples, obtaining current and wave data, or serving as a stable platform for bottom coring and diving operations.

### INTRODUCTION

Coastal engineers and surveyors working in the surf zone are all too familiar with the difficulties of accurately surveying such an active area. During high wave conditions, the mere act of collecting data, regardless of accuracy, can be a feat in itself. Conventional procedures for surveying the beach, surf zone and nearshore zones are either the use of a sea sled, which is towed offshore and surveyed as it is pulled back in, or the combination of a conventional beach survey with a boat-mounted fathometer survey. The sea sled survey offers the potential of good precision but is labor intensive, requiring a boat and crew to drag the sled offshore, a winch crew onshore, and a surveying crew. The sea sled survey is also limited by wave conditions.

High-precision surveying is almost impossible with fathometer surveys because of problems with accurately overlapping the beach and fathometer surveys, filtering out the wave effects, and accounting for tide changes. This type of surveying is also labor intensive, requiring both a land survey crew and a boat crew. Since such a large crew is required, bad weather days can significantly increase the survey costs.

This paper describes the equipment and procedures being used by the Coastal Engineering Research Center (CERC) at the Field Research Facility (FRF) for obtaining high-precision nearshore bathymetric surveys using two people, the Coastal Research Amphibious Buggy (CRAB), and a Zeiss Elta-2 total station.

#### CRAB SPECIFICATIONS AND CONSTRUCTION

The CRAB (Figure 1) was designed and built by the U. S. Army Engineer District, Wilmington for \$75,000. It is modeled after a vehicle originally built by Marine Travelift & Engineering of Sturgeon Bay for Great Lakes Dredge and Dock Company of Chicago to monitor a Corps of Engineers beach nourishment project at Rockaway, New York. An early version 25 ft high was built by the Wilmington District in 1978 to monitor beach and nearshore sediment movement at New River, North Carolina. However, to allow for a wider variety of operations in deeper water, the CRAB height was extended to 35 ft, the deck was expanded, and a davit and power winch were added. The modified CRAB was delivered to the FRF in October 1980.

The CRAB consists of a tripod of 8-inch schedule-80 aluminum tubing connected at the base by horizontal members 7 ft above the ground. Power is supplied by a 53-hp Volkswagen engine on the deck which drives a variable stroke hydraulic pump. This pump transfers hydraulic fluid at 800 psi or higher to hydraulic motors at each of the wheels. The variable stroke feature of the pump allows an infinitely variable gear ratio in either forward or reverse drive at constant engine speed. For strength and corrosion resistance, all hydraulic lines are stainless steel except for short flexible sections at the front wheel.

Total vehicle weight is about 18,000 lbs; the distance between the rear wheels is 27 ft. Though it appears top heavy, the liquid-filled tires and wide wheelbase make it very stable. It has passed a 20° tilt test and is designed to withstand even steeper angles.

Top speed of the CRAB is 2 mph on land and somewhat less in water depending on wave conditions. Since the maximum operating wave height is 6 ft, the CRAB can operate in most east coast waves and can begin surveying during the waning stages of a severe storm. The large tires have only negligible effect on a hard, rippled sand bottom; however, scour around the tires has been observed in areas of active wave breaking or strong currents. The CRAB cannot be used on soft silty or loose bottoms.

One major drawback of the vehicle is its lack of portability. Because of its size and slow speed, it cannot be driven on the highway. It is most easily moved by Chinook helicopter, but the load is near the helicopter's maximum payload weight of 15,000 lbs with the CRAB's tires drained. It can also be barged to a study area and offloaded by crane. Future CRABs could be designed to "collapse" into a mobile package for transport by truck to a new location and reassembled.

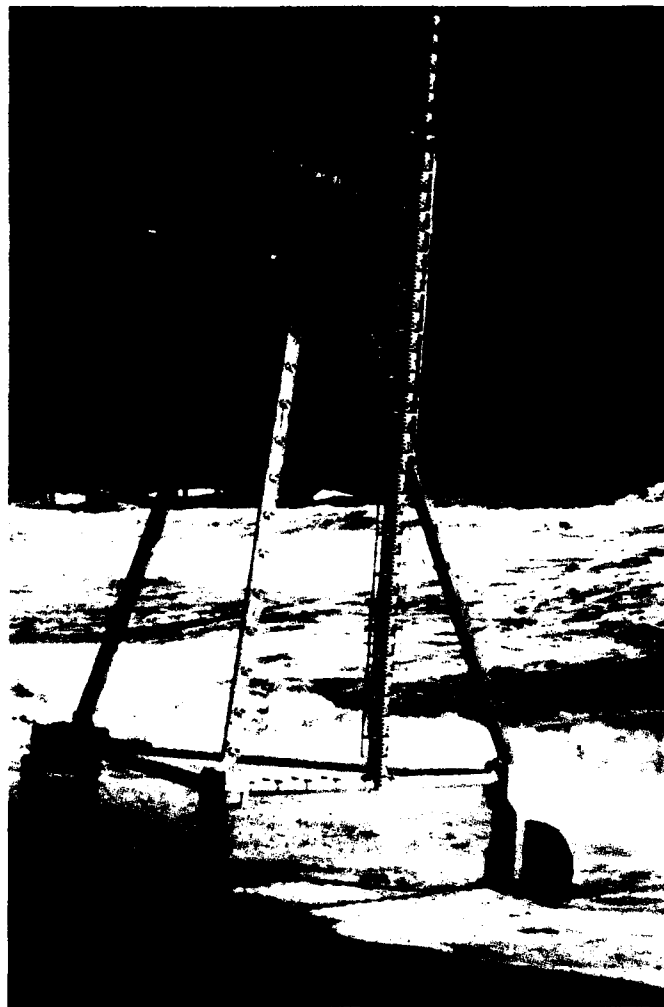


Figure 1. The Coastal Research Amphibious Buggy (CRAB) at work at CERC's Field Research Facility in Duck, North Carolina.

#### SURVEY SYSTEM

The earlier CRAB used a Motorola Mini-Ranger for horizontal positioning and an automatic level and large stadia board for elevation. With the increased range and depth capabilities of the modified CRAB, the system was no longer adequate. Therefore, a Zeiss Elta-2 surveying system with data recording capability was obtained (Figure 2). This instrument, which is considered the state-of-the-art in electronic survey systems, incorporates in one compact unit a first-order electronic theodolite, a distance meter, a microprocessor, a rechargeable power supply, and an interchangeable solid-state memory. The instrument is capable of automatically reading horizontal and vertical angles to  $\pm 0.6$  sec and, in its most accurate mode, is able to measure distance to  $\pm 0.02$  ft or better.

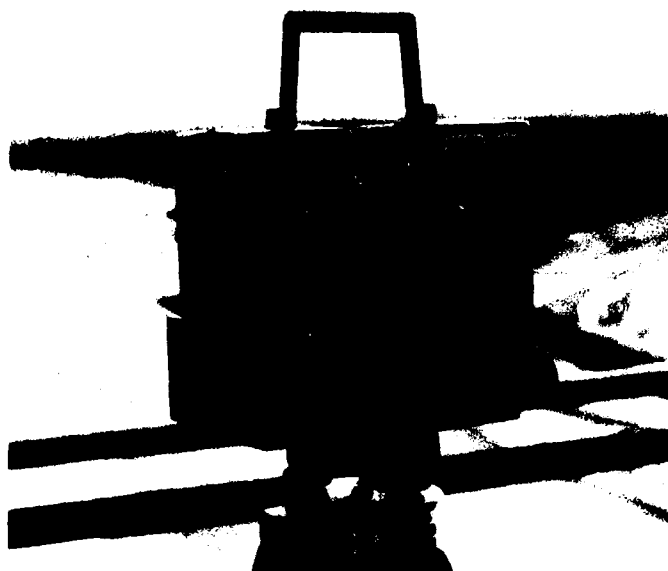


Figure 2. Zeiss Elta-2 electronic surveying instrument.

The stated operating range is 1.2 miles with a triple prism assembly. In actual use during repetitive surveys with the CRAB, an accuracy of  $\pm 0.10$  ft or better can be obtained in the horizontal and vertical coordinates. This results from variations between surveys due to the atmosphere, different instrument setups, and in the actual points surveyed.

When optically aimed at a reflecting prism assembly located on the CRAB, the instrument calculates, records, and displays the X, Y, and Z coordinates of the ground point under the CRAB. Only about 10 seconds are required to aim, shoot, and record each survey point. Because the actual coordinates of each point can be displayed, the CRAB can be kept on line to within  $\pm 2$  ft or better through radio communication between the CRAB driver and the surveyor. It is also possible to direct the CRAB to predetermined locations. This is most useful when repetitive surveys of complex bathymetry are planned. There is, of course, no requirement to survey profile lines since area surveying in three dimensions is possible. Land areas too steep to traverse with the CRAB are surveyed using a prism mounted on a range pole. Once a survey is completed, the solid-state memory is removed from the instrument and data are transferred from a Zeiss interface through a computer terminal to a main-frame computer or directly to a desk top or minicomputer. Because the system only requires the operator to aim it, instrument reading errors and fieldbook entry errors are eliminated. Total cost for the instrument, computer interface, and prisms was about \$50,000.

A unique feature of the Zeiss system is its ability to accept and record additional pieces of information (up to 14 digits) on every survey point. This has been useful for manually entering the angular tilt of the CRAB (up to  $14^\circ$  have been measured) which occurs on steep sections of the beach. This tilt is automatically compensated for when the data are processed.



The high accuracy of the system can be seen in Figure 3 which shows repetitive surveys of a single profile line from June to September 1981. While there is movement of the nearshore bar during the period, of greater interest is the stability (accurate to  $\pm 0.1$  ft) of the off-shore zone (deeper than 20 ft). This accuracy would be difficult, if not impossible, to obtain using any conventional bathymetric survey technique.

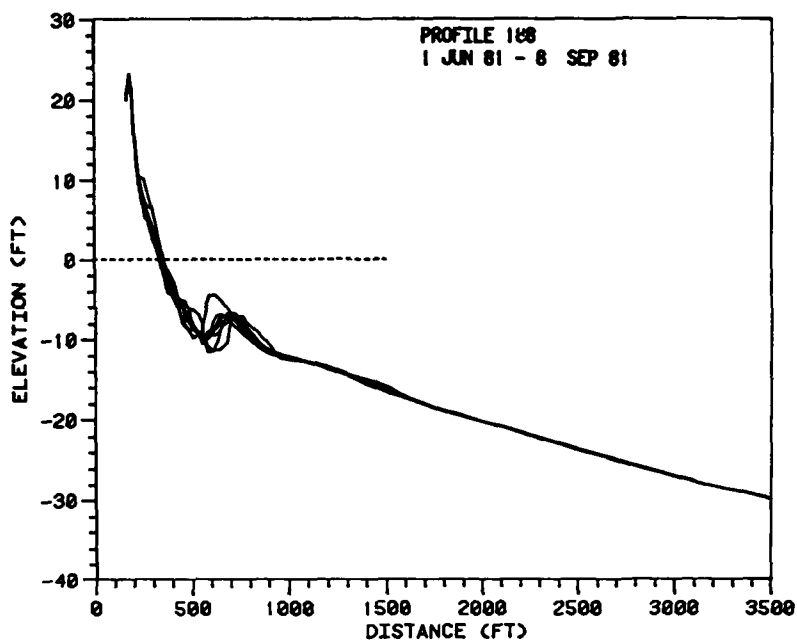


Figure 3. Sample repetitive surveys using the CRAB-Zeiss system.

#### DATA REDUCTION AND ANALYSIS

Because of the error-free nature of the data, data reduction consists of primarily reformatting the Zeiss output, adding profile numbers, dates, and times and sorting the data. This is done using the Interaction Survey Reduction Program (ISURP) developed at the FRF.

ISURP is a FORTRAN program designed to interactively process almost any kind of beach and nearshore survey data. It is a powerful software tool which allows raw fieldbook data to be entered, reduced, edited, changed, plotted, and listed. Currently, routines exist for the entry of the Zeiss type data, plus conventional survey techniques such as level and tape, and level and stadia. Routines for other techniques could be easily added.

Using ISURP, a surveyor enters, reduces, and edits the data by responding to a series of questions. Upon completion, the data are in final form and ready for further analysis. ISURP produces two types of formatted output. One is a three-dimensional data file used when X, Y,

and Z coordinates are known or needed. The second file is a two-dimensional file correctly formatted for use by CERC's new Beach Profile Analysis System (BPAS) program. Additionally, ISURP is able to read-in previously created two-dimensional or three-dimensional files if further data manipulation is required. Documentation and a user's guide for ISURP are planned though not yet available.

The BPAS system is a series of FORTRAN programs useful for analyzing and plotting beach and to some extent nearshore profiles. Up to 150 surveys of 100 profile lines with up to 60 survey points per line can be processed at one time. Major features of the program include data editing and tabulating routines, cross-sectional plotting, and shoreline and volumetric change computations. A total of 18 tables and 19 different plots can be produced. A complete eight-volume guide to the BPAS is being published by CERC.

#### SURVEY SPEED AND COSTS

The CRAB-Zeiss system has performed admirably providing reasonably fast and highly accurate repetitive surveys at relatively low cost. A survey of 50 points on a single profile line 3,500 ft long can be surveyed in about 45 minutes. A total of 22 adjacent lines (approximately 1100 to 1400 survey points) can be surveyed in 2 days. Only two people are required though an additional person to set range markers to help keep the CRAB on line is desirable. All the data can be processed through ISURP in 1 to 2 hours.

During a normal survey, the instrument is located at a point of known coordinates from which the entire area to be surveyed can be seen. (Note that the Zeiss Elta-2 has the capability to free station itself at a point of unknown coordinates by targeting 2 to 4 points of known coordinates.)

The survey proceeds from shore with the CRAB operator using the range markers to stay on line along with guidance from the instrument operator. Since in this mode the CRAB must stop at each point, it is desirable to survey the minimum number of points needed to define the profile cross section. Survey points are selected by timing the travel of the CRAB. Points are taken every 10 seconds (approximately 20 ft) near the shoreline where the bottom changes are most pronounced. The time interval is gradually increased to a maximum of 50 seconds offshore (100 ft).

Cost savings using the CRAB-Zeiss system have been significant. For example, contractual cost for a conventional quarterly bathymetric survey of 26 profile lines at the FRF was about \$35,000. Thus costs for 1 year of such surveys exceed the total cost of the CRAB-Zeiss system. Current costs for doing this work are about \$1,000 per survey plus an equipment amortization of \$4,000. Most of this dramatic savings comes from the reduction in personnel from the eight people required for the conventional survey using a sea sled nearshore and a fathometer offshore to the two people required for the CRAB-Zeiss system. Other intangible benefits of the system are reduced office time, faster data analysis, and higher accuracy. Downtime is also reduced since the CRAB can operate in more adverse wave conditions than possible during conventional surveying.

#### MULTIPURPOSE USES

Besides its surveying duties, the CRAB has performed a wide variety of tasks in the nearshore zone. Geologists have used the CRAB for collecting sediment samples and cores. Surface samples were obtained by lowering a grab sampler from the deck of the CRAB; cores were collected by lowering a 30 ft vibracorer from the deck. Shore parallel and shore normal variations in waves and currents have been monitored by using the CRAB to pull an instrumented sea sled.

Other uses of the CRAB are side-scan sonar surveying, bottom photography, underwater cable laying, and instrument deployment and recovery.

#### SUMMARY

The CRAB-Zeiss survey system provides a unique means of performing fast cost-effective nearshore surveys. In depths less than 30 ft, this system is more accurate, generally faster, less expensive, and uses fewer people than conventional bathymetric survey methods. The one major drawback is the CRAB's lack of portability. Therefore, it is best suited for use in large coastal projects or study areas. New versions of the CRAB should be designed to either collapse or to be taken apart for increased portability.

#### ACKNOWLEDGMENT

Results presented herein, unless otherwise noted, are based on research conducted at the Coastal Engineering Research Center under the Coastal Engineering Research Program of the U.S. Army Corps of Engineers. The findings reported are not to be construed as an official Department of the Army position unless so designated by other authorized documents. Permission to publish this information is appreciated.

SESSION VI: HYDROGRAPHIC DATA PROCESSING



Bill Bergen  
Jacksonville District  
Chairman



James Sheriff  
Jacksonville District



Jim Reaves  
Mobile District

NOTE: Lt. j.g. Dale Ross, NOAA,  
also speaker. Picture not  
available.

## SESSION VI

### HYDROGRAPHIC DATA PROCESSING

#### Summary

The three speakers, representing two separate Corps districts and the National Ocean Survey (NOS), discussed methods of encoding and manipulating hydrographic and topographic data bases. Many of the points brought out in these discussions lead to the conclusion that this area of Corps activities has a high potential for a Corps-wide centralization and standardization.

Centralizing and standardizing of hydrographic field procedures and techniques, data processing techniques, and data base formatting would benefit both the Corps and other federal agencies who need to assimilate Corps-generated survey data (i.e. NOS, U. S. Geological Survey, Bureau of Land Management, etc.).

Standardization of these processes could lead to resource/manpower sharing between districts--including such items as plant, instrumentation, survey crews, contractor survey forces, etc. In order to share resources, standardized procedures and techniques are important.

It is hoped that some of the above observations will be addressed by the newly formed technical user/working groups.

## AUTOMATED HYDROGRAPHIC DATA PROCESSING IN THE JACKSONVILLE DISTRICT

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### BIOGRAPHICAL SKETCH

James F. Sheriff is a Civil Engineering Technician in the Jacksonville District Engineering Division. His primary duties involve the automated processing and computation of volumetric quantities for contracted construction payment -- primarily on dredging projects. He has attended the Southern Technical Institute in Marietta, Georgia, the University of South Alabama in Mobile, Alabama, and Florida A&M University in Tallahassee, Florida. Prior to coming to the Jacksonville District, Jim was employed for 5 years by Riley, Park, Hayden in Atlanta, Georgia. Jim is a member of ASME.

### ABSTRACT

The Jacksonville District, U. S. Army Corps of Engineers' hydrographic survey data are automated in two ways -- "digitizing" and "magnetic tape". Although "magnetic tape" is the quickest way to process survey data, erroneous information is undetectable because of unknown parameters. The sensitivity of the automated equipment occasionally records extreme turbidity, schools of fish, and other variables; thereby causing erroneous data to be stored on the magnetic tape. Digitizing is the most reliable method because the operator screens each cross section as the data are input via the "electronic pen". After each survey is processed and stored on the computer, it is available for many uses. One use is the volumetric quantity computations of pre-dredge and after-dredge surveys. Usually the computations are completed within three days after the survey is plotted. These computations are critical for pay purposes within the district. Minimum effort and maximum production cause increased efficiency because survey data are automated.

### INTRODUCTION

During 1981, the Jacksonville District, U. S. Army Corps of Engineers, Survey Branch, processed 262 surveys by automation. Each survey produced an average of three sheets of plotted data, resulting in around 800 total plotted sheets. These values do not include any A-E contracted surveys. The magnitude of Survey Branch's

workload during the past year would have been impossible to meet without automated methods. The survey data not only required digitizing and plotting but also required the computation of material quantities for pre-dredge and after-dredge surveys.

#### HYDROGRAPHIC SURVEYS

The four types of hydrographic surveys processed by the Automated Processing and Computing Section are:

1. Range/range or multi-range - fully automated survey system.
2. Range/azimuth - electronic measuring device with Theodolite at same point, distances greater than one mile.
3. Range/arc - electronic measuring device with or without Theodolite at the same point, distances less than one mile.
4. Baseline - includes all conventional methods of surveying.

Although processing each of these surveys is approached differently, the end results are the same, a high quality product.

#### PROCESSING

Hydrographic surveys are processed by three methods - "digitizing", "magnetic tape", and "field book entry". A five-step procedure is required to reach the final plot.

First, the magnetic tape is "read" onto the "Harris" disc in raw form and stored in a temporary file. Digitizing is "read" with the "electronic pen" via the Tektronix 4054 and is also stored into a temporary file. The field book entry is "read" by direct input from the terminal keyboard. This entry supplements the other two processes by additional data along bulkheads, etc.

Second, the mag tape temporary file is reformatted for compatibility with the data adjustment and smoothing program.

Third, the mag tape data are processed by the adjustment and smoothing program, depending upon one of three plot packages - (1) true vessel plot: data are interpolated and placed on varying station and range wherever the survey vessel traveled; and are plotted by X and Y coordinates; (2) partial - smooth plot: data are interpolated and soundings placed on even 100-foot stations

with varying ranges and are plotted by X and Y coordinates; and (3) fully-smoothed plot: data are interpolated and placed on even 100-foot stations with soundings along each cross section every 25 feet, plotted by station and range. The digitized data are processed by the method in which they were surveyed; range azimuth - fully smoothed plot, range arc - true vessel plot, tagline and baseline - fully smoothed plot.

Fourth, both the magnetic tape and the digitized files are "sorted" in ascending order by " X coordinate; or, Y coordinate; or, station; or, range; depending upon the type of plot desired. The field book entry file, if such a file exists, is combined with either processed file before sorting.

Fifth, all files are "sifted" to prevent overprints within the final plot. A comparison is made between the station and range values of each sounding; if two values are the same, one is indiscriminately eliminated from the final plot file.

Digitizing is our most reliable method of converting analog data (fathometer chart) into a final plot. Each cross section is reviewed by the operator during this process. He adjusts for tide, squat, and plotter lag correction (if an automated system was used to perform the survey). The operator uses an "electronic pen" to lift the soundings from the analog record, providing X and Y coordinates or station and range for each sounding stored in the computer memory. The operator also checks for any abnormalities in the tide/draft line or the speed-of-sound line (calibration lines on fathometer chart) and makes adjustments to the data accordingly. The "Tektronix 4054" CRT plots a graph as the operator completes the digitizing cycle; if any errors occur in the graph, he can reject/repeat the line.

Magnetic tape processing is quicker to process but extensive checking is done to insure accuracy of the soundings. Sometimes erroneous data (extreme turbidity, schools of fish, or glitches) are stored on the magnetic tape; thereby causing blank spots or inaccurate soundings in the final plot. The best checking procedure is visual inspection of cross-sectional plots via the Tektronix 4054 CRT where in about two hours approximately 200 sections can be reviewed and copies produced for further study. Unfortunately, a few "glitches" are unnoticed and erroneous data are plotted even with the best checking procedures due to the unknowns of magnetic processing. Since all final plotted surveys are stored on magnetic tape within the ADP Center, they are readily available for volumetric quantity computations.



Field Book Entry is conventional survey data input direct from the keyboard. This catchall process generates and stores on the computer a permanent record primarily in quantity computations. It replaces the punch card data entry method.

#### QUANTITIES

Automated volumetric quantities are computed relative to the design and over depth templates of trapezoidal channels using the "average-end-area" method. The volume of material equals the sectional area in square feet, multiplied by the distance between each section, divided by twenty-seven, yielding cubic yards. ( $V = Ad \div 27$ ).

Computations for trapezoidal channels are easily accomplished, although turning basins and widener areas require setup time due to unusual trapezoidal templates. These unusual shaped templates require a horizontal toe slope to change the varying toe values of the channel. The horizontal toe slope is defined as the slope of the channel toes relative to the channel centerline. This is the change in range value divided by the change in station value. This 8-digit number is multiplied by the distance from the beginning of the widener area or turning basin to the end of the computation area in increments of 100 feet where this value is added to the starting toe value; thereby computing a toe value for the respective section.  $((A-B_1, B_2, \dots B_A) \times \text{Delta} + \text{toe} = \text{new toe value})$ . When the horizontal toe slope is used the vertical slope value changes accordingly, because the angle of sounding is not perpendicular to the channel; therefore, a new slope value is computed by: original slope, divided by the cosine of the ARC tangent of the horizontal toe value.  $(\cos (\arctan (\frac{\Delta R}{\Delta S})))$ .

Pre-dredge quantity computations are very important because they are the cubic yard basis for payments made to the dredging company. Also partial payments may be made during the dredging operation. Likewise, after-dredge computations are computed similar to the pre-dredge, with the exception of the Boxcut and the slope tolerance line. The "Boxcut" is the material remaining on the upslope capable of falling into an area overdredged adjacent to the channel toe; and is subtracted from the sectional quantity giving credit for the overdredging.

The side slope tolerance line is defined as a straight line passing through the following three points: (1) a point on the channel bottom line located one-fourth channel width from the channel centerline, (2) a point two feet vertically above the intersection of the required side slope line with the channel bottom line, and (3) the point

at which the line extended through points defined in (1) and (2) intersect the required side slope line.

#### ACKNOWLEDGEMENTS

Many thanks to Mr. William A. Bergen, Chief, Survey Branch, and Mr. Ted A. Self, Chief, Automated Processing and Computing Section (my supervisor), not only encouraging me to write about our program development and processing methods; but also their personal conferences regarding this paper.

SURVEYING AND PROCESSING  
HYDROGRAPHIC AND TOPOGRAPHIC  
DATA ON THE COOSA RIVER

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BIOGRAPHICAL SKETCH

Jimmy W. Reaves received his Bachelor of Science Degree in mathematics and chemistry from Delta State College. He served as a Geodesist with the Inter American Geodetic Survey in Central and South America from 1961 to 1972. Mr. Reaves transferred to the Mobile District Corps of Engineers in January 1972 where he is presently the Chief of the Cartography, Geodesy and Photogrammetry Section. He did take time out for a two-year assignment with the Corps of Engineers in Jubail, Saudi Arabia.

ABSTRACT

Congress directed the Corps of Engineers to initiate studies to determine the feasibility of making the Coosa River navigable from Montgomery to Gadsden Alabama. The scenic and sinuous Coosa River Project is approximately 200 miles long and presently has five dams with private powerhouses at each. One of the requirements for data required production of 1:2400 scale (1" = 200') planimetric map sheets with 2-foot contours in the spoil areas and hydrographic range data overprinted every 500 feet for the whole project. Support was also required to layout and tie horizontally and vertically core drill holes for the Geotechnical Branch. Detail surveys were also conducted at 16 major relocation sites. The major obstacle was to produce the required data in a very compressed time frame of 13 months.

PROJECT REQUIREMENTS

A request was received on 12 August 1980 to produce planimetric maps at a scale of 1:2400 for approximately 193 miles of the Coosa River Project. In adjacent areas scattered through the project were 50 disposal areas to be mapped with a 2-foot contour. Hydrographic ranges were to be established and monumented every 1,000 feet with state plane coordinates and NGVD elevations established on each end of every range. The hydrographic data was to be incorporated into the planimetric/topographic mapping. The Scope of Work was finalized in conference on 10 September 1980.

Field surveys were initiated the first week of October 1980 and the first 14 miles of hydrographic ranges were layed out by mid-November. The first major change in the scope of the project occurred at this point. The

start of the project was moved downstream 2 miles and the project was extended upstream 5 miles.

Hydrographic ranges were now required to be taken every 500 feet with no extension of time to complete the project. A new requirement was placed upon the section to digitize all hydrographic data in digital format for the Hydraulics Branch because of a shortage of personnel in their section.

#### RESOURCE EVALUATION

At the beginning, it was apparent that there would be a large volume of data to process. The required horizontal and vertical control with associated computations were to be accomplished by A-E Survey Contract Services. But how could the 1750 hydrographic ranges and overbank cross sections be smoothly integrated into the mapping?

What was needed was an automated hydrographic survey system that would operate from batteries in an open 18-foot skiff with a ranging accuracy of 0.1 foot in the track mode and 0.01 foot in the static mode.

Many of the hydrographic survey equipment manufacturers were contacted but none had a usable product. No manufacturer was found that was interested in development of a total system because there was not a large-enough market for the product.

In a meeting, with the A-E Survey Contractor performing the hydrographic surveys, it was decided that he would use a Model 112 Geodimeter for ranging and voice-fix mark for the fathometer chart would be transmitted via radio to boat. The Contractor shortly had his radios modified with a pushbutton to transmit a fix-interval tone to the boat.

The District's Computer Systems Branch worked closely with us and shortly developed a digitizing program that would scale the horizontal distance on the fathometer charts and reduce the sounding to NGVD. Points were digitized along the recorded charts at all points of change, but not greater than 20-foot intervals. Overbank cross sections were typed into the computer at the same time along with coordinates, elevations, designations of the end monuments. From this data X, Y, Z is generated for every point along the section. This data is then processed by our existing programs to produce point depth plates, cross sections or contour mapping (not completely developed).

#### FIELD SURVEYS

General. The initial mobilization required eight contract survey parties to begin the layout and monumentations of the hydrographic ranges at 500-foot intervals and made the necessary observations to complete all

field work on a critical 5-mile stretch. By mid-February 1981, 12 parties were busy producing cartographic and hydrographic data for the project and the first sheets of the photogrammetric mapping were completed.

The first thirteen sheets of hydrographic data were computer plotted to overlay the planimetric/topographic mapping. This proved to be the turning point in the quality of products being produced by the four Contractors. Several ranges were parallel to the river but plotted in the middle of a bean field. There was concern when the contours of the photogrammetric mapping did not coincide with the elevation data of the hydrographic ranges. After four weekends of rework by all parties involved, order was restored. It was now evident to all, that any small error in their work would be picked up further along in the process by others. From this point on, all field parties and the photogrammetrist strictly adhered to the District's set procedures with built-in checks.

At the peak of field activity, one GS-9 Civil Engineering Technician was coordinating the field activities of all 17 A-E Survey Contract survey parties stretched over 200 miles of the Coosa River.

Vertical Control. The basic vertical control net was monumented and observed along the river system in 1978-1979. Procedures established for the 1980-1981 project required that surveys be initiated from an existing monumented mark and close upon another monumented mark. TBM's were not to be used to expand monumented control or for mapping. A peg check was made and recorded daily to assure that the instrument was in proper adjustment. Notes were kept with a rapidograph type pen in black ink using a No. 1 pen point.

Horizontal Control. The basic horizontal control net and river traverse were monumented and observed in 1978-1979 using a Wild T-2 Theodolite. Procedures established for controlling the hydrographic ranges were to run a random traverse and spur tie range monuments. Traverse angles would be turned four times and spur angles twice, using a Wild T-2 Theodolite. One observation was set as follows: initial on backsight turn to foresight and read, turn to backsight and read, plunge instrument and read, turn to foresight and read, turn to backsight and read. Observer was required to check observation and computations before the setup was broken. Height of instrument and target were recorded and the vertical angle measured. EDM measurements (including temperature and PPM setting) were recorded in the horizontal book with the angle measurements.

Hydrographic Observations. The overbank profiles were observed using a level, rod and tape from the 0+00

monument to the first point in the river where hydrographic sounding could be made. Field book and page number were noted on the hydrographic charts along with the date, time, range name, and water surface elevation.

Except for the lake areas where ranges were 1-1/2 to 3 miles long, the river ranged from 300-500 feet in width. The Model 112 Geodimeter was set up at a point near the water edge to keep the elevation of the instrument and reflector within 1-1/2 feet of each, in order to keep the slope and horizontal distance within 0.1 of a foot.

The reflector was placed in the boat on swivel pole along side the fathometer transducer. The reflector was constructed by mounting a triple prism in the center of a 2-foot square sheet of aluminum and then surrounding the prism with white highway reflectors. The highway reflectors are necessary to spread the return beam of light when measuring short distances. The triple prism was adequate to measure lines as long as 3-1/2 miles.

The fathometer was bar checked in the morning, at noon, and at the end of the days' work. The only difficulty encountered on this phase of the work was obtaining reliable reading when the water depth was less than 3 feet.

#### PROCESSING DATA

General. Mr. Donald Thrower, GS-9 Civil Engineering Technician, Corps of Engineers, coordinated all of the field activities and submitted the completed cross-referenced field data in blocks to the District office. All data at this point had been checked and necessary computations and reductions were made by contract field personnel.

For processing and plotting purposes, each of the six reservoirs were set up in the computer as separate projects. One GS-4 Surveying Technician and one GS-3 Engineering Co-op Student were assigned to enter the data into the Hydrographic Automated Survey System (HASS) via a Tektronics terminal and digitizer. Processing started at the downstream at 0+00 and progressed upstream to the end of project. Blocks of data can be entered at each terminal and then be reorganized in the master file in sequential order.

Operating the Programs. This terminal user's guide represents the interaction of the terminal operator and the computer by the following typographical conventions.

**BOXED CAPITALS** and numerals denote entries you must make on the terminal keyboard.

REGULAR CAPITALS and numerals represent computer prompts and messages on the CRT.

UNDERLINED CAPITALS denote sections of the guide.

CR represents a carriage return.

Beginning Execution. After you have signed on, the computer will display this message on the CRT:

THIS TERMINAL IS READY FOR YOUR USE.

To execute a HASS program, enter  CR on the terminal keyboard. The system will respond

WELCOME TO THE HYDROGRAPHIC AUTOMATED SURVEY SYSTEM.

ENTER THE PROCESSING TASK NUMBER TO BE EXECUTED.

(ENTER  TO GET A LIST OF PROCESSING TASKS.)

You may now enter the number of the particular HASS task you want performed or  CR to get this list:

PROCESSING TASK	NUMBER
LIST PROCESSING TASKS	<input type="text" value="00"/>
WRITE EOF MARK OF A CASSETTE	<input type="text" value="01"/>
CASSETTE TO DISC TRANSFER	<input type="text" value="02"/>
RAW SURVEY DATA EDIT	<input type="text" value="03"/>
OUTPUT PRODUCTS DATA FILE CREATION	<input type="text" value="04"/>
LOCATION AREA MAP PRODUCTION	<input type="text" value="05"/>
POINT DEPTH MAP PRODUCTION	<input type="text" value="06"/>
UNLOAD SURVEY DATA FILES FROM DISK ONTO MAGTAPE	<input type="text" value="07"/>
LOAD A SURVEY DATA FILE FROM MAGTAPE ONTO DISK	<input type="text" value="08"/>
COORDINATE RESEARCH OF OUTPUT PRODUCTS DATA FILE	<input type="text" value="09"/>
CROSS SECTION AND WATER SURFACE DATA FILE BUILD	<input type="text" value="10"/>
CROSS SECTION AND WATER SURFACE PLOT PROGRAM	<input type="text" value="11"/>
CROSS SECTION DIGITIZING DATA ENTRY PROGRAM	<input type="text" value="12"/>
CROSS SECTION TO POINT DEPTH DATA CONVERSION	<input type="text" value="13"/>
CROSS SECTION LOCATION AREA MAP PLOT PROGRAM	<input type="text" value="14"/>
TERMINATE HASS	<input type="text" value="99"/>

Digitizing Cross Section Data. Enter  for digitized data entry. The beginning prompts and responses are the same as those of the File Build program, but after you enter the name of the cross section this program asks DO YOU WANT COORDINATES STORED (Y,N)?

:

☐ Y : ENTER NORTHING BEGINNING OF RANGE.  
ENTER EASTING.  
COORDINATES (C) OR AZIMUTH (A) FOR EOR.

Azimuths.

☐ A : ENTER AZIMUTH (DEGS, MINS, SECONDS) TO END OF  
RANGE.  
SELECT STATE AND ZONE NUMBERS.  
ENTER 30 TO LIST OR 999 TO END.

Enter the zone number or ☐ 30 . ( ☐ 999 is used only to leave this routine if it was entered inadvertently.) The program will convert the state grid entry (northing and easting components) to a geographic position in degrees of latitude and longitude. It then prompts for distance and elevation, checks for an alphabetical prefix (if any) to the distance, and performs different functions according to the prefix. The procedure is the same as that performed by the File Build program.

Coordinates.

☐ C : The procedure with coordinates is the same as with azimuths except that after your entry of a zone it prompts you to ENTER NORTHING EOR and EASTING before performing the conversion.

Whether you entered azimuths or coordinates, the program's next prompt is to

ENTER DISTANCE AND ELEVATION.

ENTER 'Z' FOR DISTANCE WHEN SECTION IS COMPLETED.

This is the prompt issued if you responded ☐ N when asked if you want coordinates stored. The program now performs different functions according to the prefix (if any) of your distance entries, as described in the corresponding portion of the File Build program.

If you inadvertently enter a letter along with the digits for the water surface elevation, the program will respond ERROR IN ELEVATION READ and prompt for another entry. When your entry is acceptable, the program displays the following prompt:

TO CONTINUE KEYBOARD INPUT, ENTER 'C' ELSE RETURN.

☐ C : Continue distance and elevation prompts until entry of a CR . This process enables you to insert depths which have had to be determined manually because of the shallowness of the water between the water's edge and the first of the fathometer soundings.



CR : The program displays the following instructions:

DIGITIZE XSCALE ON CALIBRATE LINE, ENTER 'S,'  
RETURN.  
THEN DIGITIZE PTS ON FATHOMETER SCROLL.  
ENTER 'S' THEN RETURN.  
ENTER 'Q,' RETURN TO STEP DOWN SCALE 50 FT.  
ENTER 'R,' RETURN TO STEP UP SCALE 50 FT.  
ENTER X VALUE OF START POINT ON CALIBRATE LINE.

First enter the X value of the starting point of the calibrate line, i.e., the intersection with the first vertical pencil line on the fathometer scroll. (If you do not know this value, you may find it on the scroll.) Then move to the graphics tablet where the scroll is fastened and digitize the calibrate line, being careful to observe the following procedures:

1. When the READY light on the power module is lit, slide the hand-held cursor across the tablet until the cursor's cross hairs are positioned exactly on the starting point of the calibrate line.
2. Press the button on the cursor to digitize this point.
3. Slide the cursor to the next vertical line and press the button when the READY light is lit. When you encounter an especially wide vertical pencil line, digitize at the nearer, or left-hand, side of the line.
4. Always be careful to keep the cursor flat on the scroll. Lifting it even slightly introduces an error and causes an electronic beeping sound. If this should occur, return the cursor to the tablet and redigitize the last point.
5. Continue digitizing each intersection of the vertical pencil lines with the calibrate line.
6. If the program detects erroneous data, the terminal will beep 3 times. Redigitize the last point if this happens.
7. After digitizing the final point on the calibrate, i.e., the far-right vertical line, enter  on the terminal.
8. Return to the tablet; slide the cursor to the intersection of the far-left vertical line and the fathometer curve. When the READY light is lit, follow the curve and press the button at every significant change in direction. Always digitize on the upper surface of the curve.

9. If the curve is longer than the tablet, mark a stopping point (at the same vertical line) on both the calibrate line and the curve. Digitize both, being sure to enter **[S]** at the stopping point of the calibrate line and **[T]** at the stopping point of the curve. Then without raising the cursor realign the scroll on the tablet and digitize from the stopping points.
10. When the curve dips very close to the calibrate line, it breaks off and is continued near the top of the scroll. In these cases, digitize the last point before the break and enter **[Q]** on the keyboard. If there is no break, simply continue digitizing. (Skip to Step 14.)
11. Return to the scroll, slide the cursor cross hairs to the first point of the continuation at top, and press the button.
12. Continue digitizing this part of the curve to its end, then enter **[R]** on the terminal.
13. Return to the scroll, slide the cursor cross hairs to the point at which the original curve resumes, and press the button.
14. Continue following the curve and digitizing until you reach the intersection of the curve and the last of the pencil lines. Digitize here but go no farther.
15. Return to the terminal keyboard and enter **[S]** .

The program will now display this message:

TO CONTINUE KEYBOARD INPUT, ENTER 'C' ELSE RETURN.

**[C]** : Continue distance and depth prompts until CR . This enables you to enter points between the end of the scroll and the water's edge.

CR : ENTER DISTANCE AT WATER'S EDGE. The program will then prompt for distance and elevation beyond the water's edge. Enter them from the field notebook and remember to indicate a monument, plastic hub, etc., by prefixing the appropriate letter. Enter **[Z]** for the final distance when the cross section is complete.

The program will now display the cross section on your CRT, along with a pair of cross hairs which may be

manipulated by the directional controls at the bottom right side of the Tektronix keyboard. At the bottom of the screen it displays this prompt:

TO CORRECT A POINT, POSITION CROSS HAIR, ENTER 'P.'  
ENTER 'N' IF OK.

If corrections are needed, rotate the controls until the cross hairs meet at precisely the point to be changed. Enter a  and then the correct distance and elevation on the keyboard. The program will incorporate the correct point in its redrawing of the section and then offer the opportunity to make other corrections.

If you are satisfied with the cross section displayed on the screen and want a copy of it, press the COPY button on the Tektronix Hard Copy Unit before entering .

After the , the program will write the data on the file and ask if you want to digitize another cross section. A response of  causes the program to return to the beginning. An  here returns control to HASS, which offers the opportunity to execute other programs.

Cross Section to Point Depth Conversion. Enter  to convert digitized data to point depth format for use by the location area program (option 05) and the point depth map production program (option 06). This program will first prompt you to enter the name of the cross section file that is to be converted and then the name of the point output file. After you enter the output file name, it asks IS THIS A NEW FILE (Y OR N)? The program will display an error message if you answer  but the file name already exists. The program will now execute, prompt you to ENTER INVENTORY FILE NAME, and ask IS THIS A NEW INVENTORY FILE (Y OR N)? It calls the Output Data File Creation program (option 04), and when that program has finished control returns to the HASS list of processing options.

Cross Section Location Area Map Plot. Enter  to plot location area maps. The program will prompt you ENTER NAME OF CROSS SECTION FILE TO BE MAPPED and then ask DO YOU WANT TO PRODUCE A LOCATION AREA MAP? IF SO, ENTER 'YES'; IF NOT, ENTER 'NO.'

: Stop execution and return to the list of HASS options.

: The program prompts for a two-line title block and a two-line survey description. Then in a series of screen displays it shows the smallest and largest X and Y coordinates, the number of records in the file, and

the minimum scaling factor required to produce a location area plot that uses all of the records in the file. It next issues the following prompts:

ENTER THE LENGTH OF THE EASTING-AXIS IN INCHES.  
ENTER THE LENGTH OF THE NORTHING-AXIS IN INCHES.  
ENTER THE SCALING FACTOR IN FEET/INCH.  
ENTER THE MINIMUM EASTING-COORDINATE.  
ENTER THE MINIMUM NORTHING-COORDINATE.

The program displays the values you enter and asks if they are correct.

☐ NO : Stop execution and return to the list of HASS options.

☐ YES : Perform the required computations and begin the plot. The program will then ask again if you want to produce another location area map plot. This process will continue until you enter ☐ NO .

Point Depth Map. Enter ☐ 06 to produce point depth maps. The program will ask for your qualifier and then ask DO YOU WANT TO PRODUCE A POINT DEPTH MAP? IF SO, ENTER 'YES'; IF NOT, ENTER 'NO' TO STOP.

☐ NO : Stop; return to HASS option display.

☐ YES : Prompt for 2-line title and 2-line description of the desired map. Prompt for the name of the edited hydrographic survey file (input), map size, scale factor, and minimum easting and northing coordinates. Finally, the program asks whether all data points are to be plotted or overplotting of consecutive points is to be suppressed.

When the program has performed its computations and begun its plotting, it returns to the first prompt shown above and offers the opportunity to produce another point depth map. This process continues until you enter

☐ NO .

#### MAP COMPILATION

The basic planimetric/topographic mapping was accomplished by photogrammetric methods on a PG-2 stereo plotter. The stereo plotter manuscripts were then scribed into the final sheet format. A standard title block and border were scribed for the first overlay. A sheet index was scribed for each reservoir which was used as the second overlay.

Two procedures were used to produce the hydrographic point depth data overlay. The District's computer center plotted the point depths on vellum for each map sheet of the Coosa Project. For approximately half of the map sheets produced, the vellum was used as a direct

overlay. It was found that if a full-size photographic negative was made of the computer plot and that used as the overlay, the quality of the finished product was greatly improved.

#### SUMMARY

Hydrographic ranges surveyed	1750
Number of reservoirs	6
Spoil areas mapped at 1" = 200'	
with 2' contour	50
Map sheets at 1" = 200'	415
Core drill holes - layout and	
tie horizontally and vertically	427
Total time of project	13 months
Number of party days	2600
Maximum number of parties	17

CORPS OF ENGINEERS DIGITAL DATA  
FOR  
NATIONAL OCEAN SURVEY NAUTICAL CHARTS

V. Dale Ross  
Lieutenant (jg), NOAA  
Marine Chart Division  
National Ocean Survey  
National Oceanic and Atmospheric Administration  
Rockville, Maryland 20852

BIOGRAPHICAL SKETCH

Lt. (jg) V. Dale Ross is a civil engineering graduate of Drexel University. He began working in hydrography with a Philadelphia District, Corps of Engineers (COE) field party. In 1978, he joined the NOAA Corps serving on a hydrographic survey ship in Alaska and Hawaii. In January 1981, Lieutenant Ross was transferred to his present position at National Ocean Survey (NOS) headquarters on the Marine Chart Division staff. Lieutenant Ross is primarily involved in obtaining COE digital hydrographic surveys and developing processing procedures for applying the surveys to published NOS nautical charts. He is a member of ASCE, SAME, ACSM, ASEM, and the Hydrographic Society.

ABSTRACT

National Ocean Survey (NOS) receives data from over 60 sources, some of which collect data in digital form. NOS would like to receive and be able to process digital data from outside sources by automated methods. NOS is developing an automated data bank to store, retrieve, and process data for maintaining nautical charts. In an effort to improve efficiency, NOS has been contacting outside sources to set up a mutually beneficial exchange of digital data. NOS is cooperating with the Naval Oceanographic Office, Defense Mapping Agency, U.S. Geological Survey, and the Canadian Hydrographic Service. Recently, NOS has contacted the Corps of Engineers Districts to try to set up a similar exchange.

INTRODUCTION

The National Ocean Survey (NOS) is currently developing an automated data bank in an effort to produce nautical charts more efficiently. In keeping with this goal, we hope to receive digital data from outside sources that have digital capabilities.

The Marine Chart Division (MCD) began contacting Corps of Engineers (COE) Districts inquiring if they were using computer support for hydrographic surveying and if they would be interested in an exchange of digital information regarding the nature of each other's files and processes. Also, what types of information would

the District desire from NOS. The purpose of this paper is to apprise people in the various Districts, of our requirements and ultimate goals.

#### CURRENT DATA FLOW

Currently, the individual COE Districts routinely send a print of their engineering drawings, with any necessary notes, to the Nautical Data Section, MCD. The Nautical Data Section then registers the document and sends it to the appropriate geographic area chart compilation team. The information is reviewed by chart compilers for anything that might require immediate attention. When a critical item is found, appropriate action is taken to incorporate it in the next publication of the Local and Weekly Notice to Mariners.

If no critical items nor changes are found on a print, the document is labeled accordingly and returned to the Nautical Data Section where archiving is completed.

This method involves a large duplication of manual effort. Each update must be made to at least two chart drawings of different scales. Digital charts being maintained with digital data would eliminate the duplication since corrections would be made only once to the chart maintenance file independent of scale.

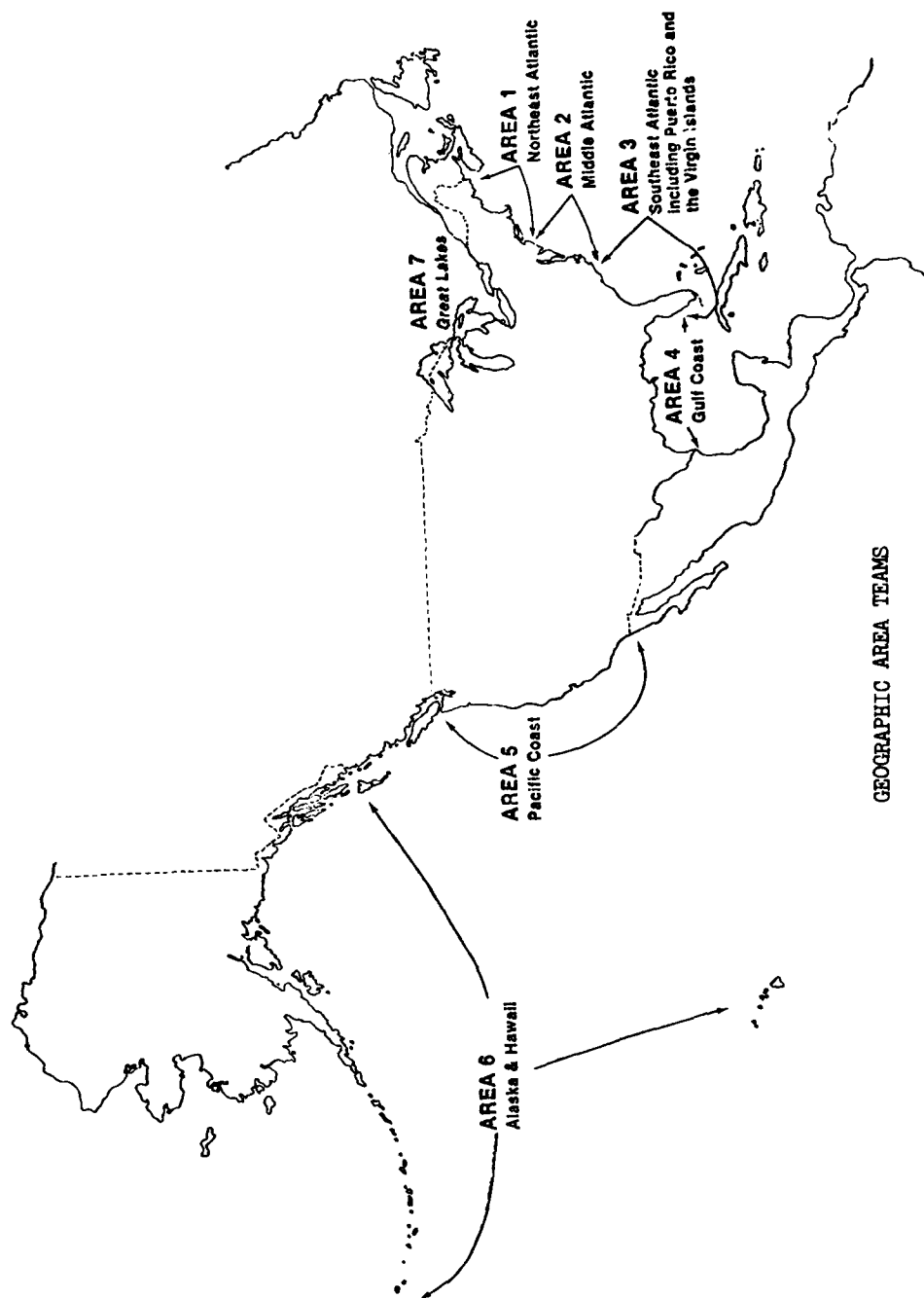
#### NOS FINDINGS

MCD has received cooperation from six COE Districts as a pilot project. The six Districts are: New Orleans, La.; Wilmington, N.C.; Buffalo, N.Y.; Baltimore, Md.; Philadelphia, Pa.; and Jacksonville, Fla. Concentration is on these Districts because they are in areas of highest priority in the NOS/Automated Information System (AIS) loading sequence.

Each of the pilot Districts have different equipment, different processing methods, and different formats. The digital data received from New Orleans District was not compatible with any NOS computer systems. Wilmington has a post-processing system and has been able to make some format changes. As part of the task, Wilmington has graciously offered to send future surveys in geographic positions in the NOS/MCD format.

Philadelphia on the other hand does only a small amount of post processing. The data received from them are in range-range format on paper tape. NOS is currently generating software to write a magnetic geographic position tape in the NOS/MCD format from their paper tapes. The program is expected to be finished in March 1982.

To process data from the Baltimore, Buffalo, and Jacksonville Districts, some sort of deblocking and record arranging routine will have to be successfully completed by NOS to make the data compatible with NOS processing software. Different alternatives are being investigated.



GEOGRAPHIC AREA TEAMS



The three Districts mentioned above forwarded their surveys in state plane coordinates which NOS converted to geographic positions.

#### FUTURE DATA FLOW

NOS hopes to be able to obtain and process digital data from outside sources as an effective tool in nautical charting. To achieve our ultimate goal, minimal impact is essential; NOS must be able to utilize submitted digital data with minimal manual effort. In the same vein, we realize we cannot significantly impact the COE Districts. However, should any of the Districts be undertaking automation, restructuring what already exists, or be in the planning stages, NOS would like those Districts to consider producing a magnetic tape in the NOS/MCD format as a byproduct of their normal processing.

Assimilating COE digital data will have to be accomplished with two phase-in periods. Initially, one or two surveys will be used for experimentation and development by MCD. Once a processing routine is established, two or possibly more surveys per month will be requested. This phase will be used to train MCD employees in the necessary steps to handle new data under a light but steady flow. This period will also give the Districts time to establish a satisfactory routine for forwarding the data. When everyone becomes familiar with the procedures, the District can become fully operational--sending all digital surveys to the Nautical Data Section as soon as they are available for distribution.

The Nautical Data Section will register the data and send it to the appropriate chart compilation team. The team will convert from state plane coordinates, if necessary, and load the tape into the new data holding file in the AIS. Once this is complete, the data can be called up on the CRT at a work station where the digital data compilation functions are performed. As in the current process, if a critical item is found, a Notice to Mariners will be issued.

A sounding plot at survey scale will be made to check against the print for errors. Then depth curve plots will be made at chart scale to assist the cartographers in applying the new data. Also, a sounding plot at chart scale will be made. Changes are entered into the published data file for the next printing of the charts in that area. The data not used from this survey will be entered into the unpublished data file for future reference. When data are superseded, they will be archived.

If the chart compiler decides a survey shows no changes to the chart, the data will be released from the new data holding file and no actions taken.

Appendix I gives a more detailed description of the NOS/MCD digital data format.

## APPENDIX I

### THE NOS DIGITAL DATA FORMAT

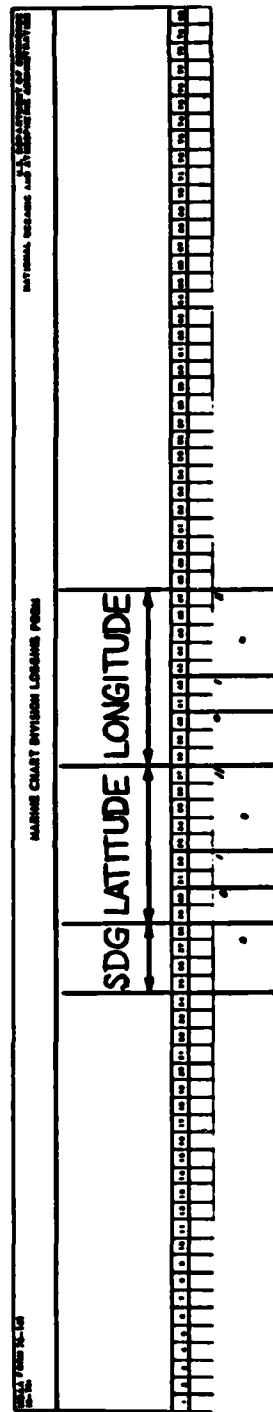
NOS prefers receiving digital data in the NOS/MCD digital data format which is based on an 80 character card image. This format combines feature identification and plotter commands with the data (figure A). Most of the information is inserted by NOS during registration and processing.

The data are contained in the block of columns 25 through 47 inclusive. Columns 25 through 28 are for the sounding, assumed to be to a tenth of a unit. Columns 29 through 37 are the latitude, assumed to be to the thousandth of a second. The longitude is in columns 38 through 47, also assumed to the thousandth of a second.

If latitudes and longitudes are not feasible, state plane coordinates can be entered in place of the latitudes and longitudes, respectively. In this case, the X- and Y- coordinates are assumed to be to the hundredth of a foot (figure B). This information is right justified; leading zeroes are not necessary but following zeroes are necessary.



# GEOGRAPHIC POSITIONS



# STATE PLANE

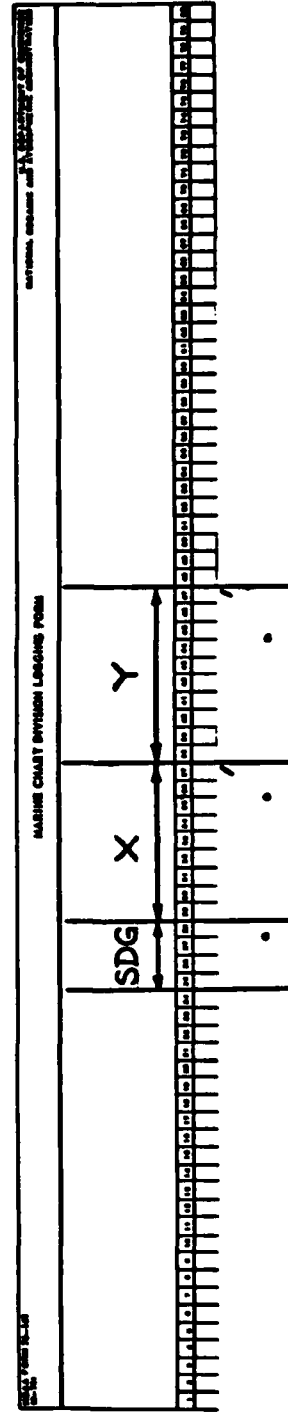


FIGURE B

SESSION VII: TOPOGRAPHIC EQUIPMENT DEVELOPMENT



Ed Roof  
ETL  
Chairman  
(also Speaker-No Paper)

*Speakers*



Lloyd Penland  
Wild Heerburgg  
Instruments, Inc.  
(No Paper)



Marshall Brown  
Keuffel and Esser Company



John Wickham  
World Survey, Inc.



Walt Senus  
DMA  
(No Paper)



Bob Brown  
International  
Technology, Ltd.  
(No Paper)

SESSION VII  
TOPOGRAPHIC EQUIPMENT DEVELOPMENT

Summary

Equipment in the fields of inertial technology, satellites, north-seeking gyros, and pulsed laser distance meters were described. Two commercial firms that utilize inertial and satellite technology in the surveying field, described their capabilities to support Civil Works survey requirements. In addition the necessity for planning, both short-term and long-term, to take advantage of newly developing technology was discussed. The cost effectiveness of using inertial surveying systems on actual projects was described.

## A PULSED GaAs LASER DISTANCE METER

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### BIOGRAPHICAL SKETCH

Marshall D. Brown is manager of the EDM/Medical Monitoring Development Laboratory at the LSE Operations Plant. He received his B.S. degree in Electrical Engineering from the University of Tennessee, Knoxville. From his graduation in 1959 until 1972, he worked in the development of instrumentation systems for ARO, Inc., the operating contractor for the Arnold Engineering Development Center. Since 1972 he has been engaged in the development of electronic distance measuring instruments for the Keuffel and Esser Company. Mr. Brown is a member of IEEE and SPIE.

### ABSTRACT

A lightweight, portable pulse GaAs laser distance meter has been developed and tested. Distance measurement techniques and design parameters related to instrument performance are presented. Instrument performance as related to target characteristics and some potential user applications are discussed.

### INTRODUCTION

Electronic distance measuring instruments have been in existence for several years. Most of them utilize a phase measuring technique and provide a high degree of measurement accuracy. This technique, however, usually requires several seconds for each measurement, and the low power light sources necessitate the use of active targets such as corner cube reflectors. Although not quite as accurate in most cases, instruments using pulsed laser techniques are capable of ranging to passive targets and provide a distance tracking capability. The instrument described in this paper provides a passive range capability up to 100 meters, a maximum range of 3 km, and an accuracy of  $\pm(30\text{cm}+30\text{ppm})$ .

### RANGING TECHNIQUE

Pulse ranging systems are in principle very simple. The transmitted pulse starts a clock, and the return signal from the target stops the clock. The time accumulated by the clock is a direct function of distance. Gating an oscillator on and counting for the measurement time results in an accumulated count that is proportional to distance. The frequency of the clock oscillator is

directly related to the resolution that can be achieved since a single clock period represents the minimum time interval that can be measured. Based on the nominal speed of light,  $2.99 \times 10^8$  m/s, a 1.5 GHz clock frequency is required to resolve a distance of 10 cm. Since counting 1.5 GHz clock pulses is very difficult, an alternate approach is used to achieve the same results. By stretching the effective time between the transmitted and the return pulses by a factor of 100, a 15 MHz frequency can be used and still maintain a resolution of 10 cm.

The return light pulse, when processed through the photo-detector and signal amplifiers, has a definite rise time, and its amplitude is dependent upon target characteristics and distance. These two factors when coupled together make it difficult to determine the precise time of the return pulse. Timing errors in the order of 2 nanoseconds produce distance errors of 30 cm. Various techniques have been used for received pulse detection. Mamou et al. (1978) describe a half amplitude detector that reduced amplitude errors to less than 10 cm for a 10 to 1 amplitude range. Barbacsy and Chaborski (1978) describe a tuned circuit pulse detector that virtually eliminates errors over a 6 to 1 amplitude range. Although these techniques perform well, they are more difficult to implement and are more orientated toward high accuracy systems. A straightforward threshold detector and pulse amplitude compensating circuit when used in conjunction with a servo driven optical attenuator provides the required accuracy and dynamic signal range.

#### SYSTEM DESCRIPTION

As shown in Figure 1, the basic ranging system consists of the laser transmitter, the pulse detector, the analog module, and the logic module.

Laser Transmitter. The transmitter consists of a three-stacked GaAs pulse laser. The emitting area is 0.008x0.009 in. and when coupled to the transmitting lens provides a transmitted beam divergence of 2.5 milliradians. The laser is driven by an avalanche transistor and produces a 20 watt peak output pulse having a half-power pulse width of approximately 15 nanoseconds. A 200 pps repetition rate is generated by a free-running oscillator.

Pulse Detector. The pulse detector consists of a 0.04 in. diameter active area PIN photo diode, two signal amplifiers, and a threshold detector. When coupled to the receiving lens, the detector has a 10 milliradian field-of-view. Two signals are produced by the detector module--one a fixed logic pulse determined by the threshold detector and the other received amplitude dependent.

Analog module. The analog circuit performs the function of time stretching and pulse amplitude correction. The time stretching technique consists of two constant current



sources. The transmitted pulse is used to turn on a constant current source, which begins to charge a capacitor. The return pulse turns off the first current source and turns on a second current source which discharges the capacitor. By making the ratio of the two current sources equal to 100, the charge and discharge times differ by this same factor. The voltage on the capacitor is fed into a gated voltage comparator which produces a clock gating pulse that is 100 times longer than the true time of flight (see Figure 2). The return amplitude dependent pulse is used to apply a correction factor to the clock gating pulse and to control the optical attenuator.

Logic module. The logic circuit consists of the master clock oscillator, the gating switches, and the counter. The corrected gating pulse from the analog circuit is used to gate the oscillator to the counter. The accumulated count is a direct indication of the range. In order to reduce the effects of system noise, 100 or 1000, operator selected, range measurements are averaged and then displayed. Since the repetition rate is 200 pps, the measurement rates are 2 per second or 1 per 5 seconds. The range data is routed to the instrument display, the external data jack, and the scope display.

The scope display consists of a LED array, two prisms, and two negative lenses. As seen in Figure 3, the prisms and lenses are positioned such that the LED image falls in the same focal plane as the crosshair.

#### RANGE PERFORMANCE

Since the receiver field of view is larger than the transmitter beam divergence, the received power from a Lambertian surface can be expressed as:

$$\begin{aligned}
 (1) \quad P_r &= \frac{P_t}{\pi} (W/SR) T_r \Phi_r (SR) \rho \cdot \exp(-2\sigma R) \\
 \text{where } P_t &= \text{transmitted power} \\
 &= 20 \text{ watts} \\
 T_r &= \text{transmission of receiving optics} \\
 &\quad (\text{optical attenuator fully open}) \\
 &= 0.8 \\
 \Phi_r &= \text{solid angle of receiving optics} \\
 &= \frac{A_r}{R^2} \\
 &= \frac{0.0066M^2}{(100M)^2} SR \\
 &= 6.6 \times 10^{-7} SR \\
 P &= \text{target reflectivity} \\
 &= 0.2 \\
 \sigma &= \text{atmospheric attenuation coefficient at sea level} \\
 &= 0.3/\text{km} \text{ (typical for a 5 km visibility)} \\
 R &= \text{range} \\
 &= 100 \text{ meters} \\
 P_r &= 6.32 \times 10^{-7} \text{ watts}
 \end{aligned}$$

The receiver sensitivity is given by:

$$(2) V_o = Q_d A_1 A_2 P_r$$

where  $Q_d$  = detector responsivity  
= 0.5 A/W

$A_1$  = transimpedance amplifier gain  
=  $10^4$  V/A

$A_2$  = video amplifier gain  
= 400 V/V

$V_o$  = 1.26 V

The threshold detector is set for a signal level of 200 mv; therefore measurements up to 100 meters can be made to targets having a reflectivity of 0.2 or greater. Tests results indicate that targets such as red brick, green house paint, and new spruce plywood have sufficient reflectivity to range 100 meters. A single 3 inch diameter corner cube reflector can be used for measurements up to 3 km.

Figure 4 indicates the range error at distances from 8 meters to just over 1 km. The distances from 8 to 17 meters are in 0.25 meter increments.

#### INSTRUMENT APPLICATIONS

The ability to range passively and track targets offers several potential user applications, some of which are:

- Docking aids
- At sea ship refueling
- Collision warning
- Bulk ore or material estimating
- Moving vehicle or vessel control or monitoring
- Hydrographics

#### LASER SAFETY

Surveying instruments having a laser light source outside the visible range are limited to a Class I category. Using the U.S. Department of Health and Human Services, Bureau of Radiological Health's Class I criteria, a laser device with a wavelength of 904nm can transmit  $4.98 \times 10^{-7}$  joules of energy in a single pulse. The actual transmitted energy/pulse is  $3 \times 10^{-7}$  J. The BRH limit for time duration between 100 and  $10^4$  seconds is  $97.6 \times 10^{-6} t$  J/s. The actual transmitted for this time interval range is  $60 \times 10^{-6} t$  J/s.

#### CONCLUSION

A portable distance meter using a pulsed GaAs laser diode transmitter has been developed. Test data indicate that the instrument accuracy falls within a +30cm error band. The instrument sensitivity is such that passive ranging can be achieved at distances up to 100 meters from a variety of targets. The time stretching technique and range averaging utilized provide a good trade off between range resolution, repeatability and maximum capability.

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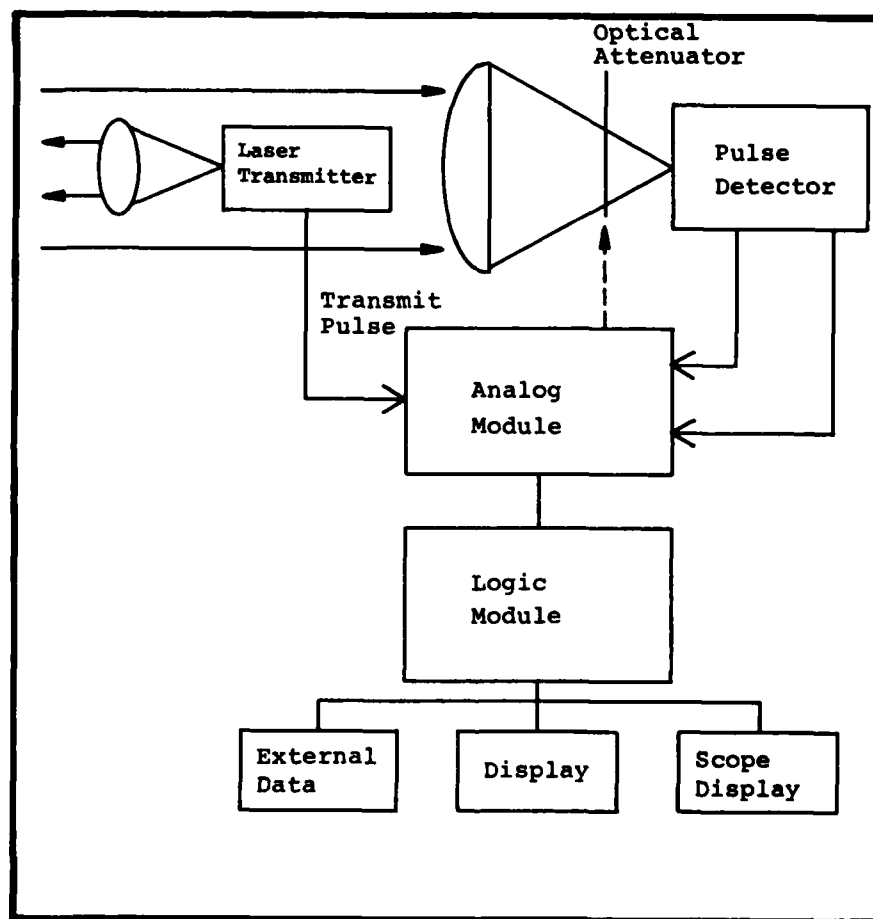


Figure 1. RANGING BLOCK DIAGRAM

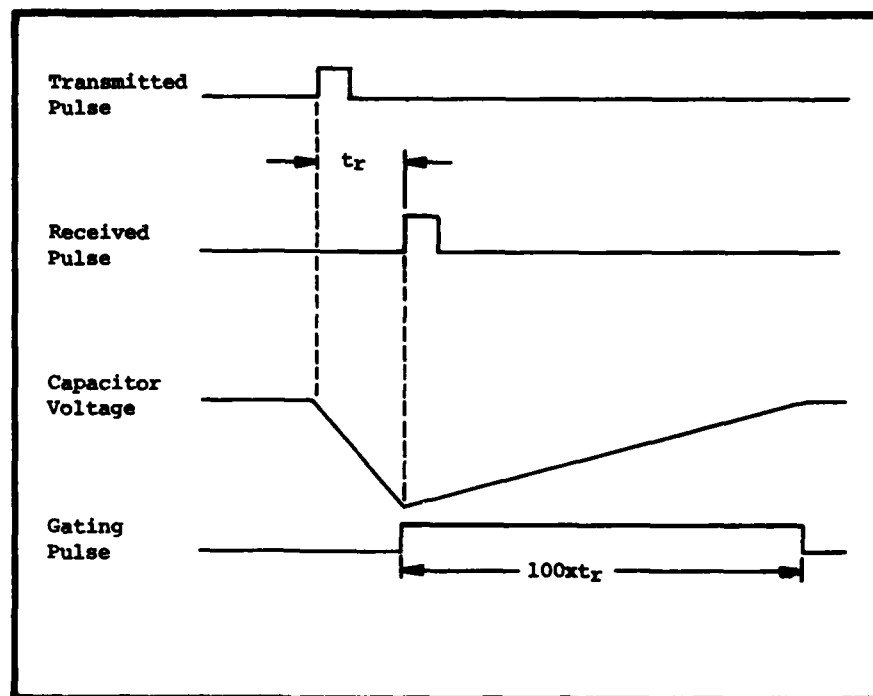


Figure 2. Time Stretching Diagram

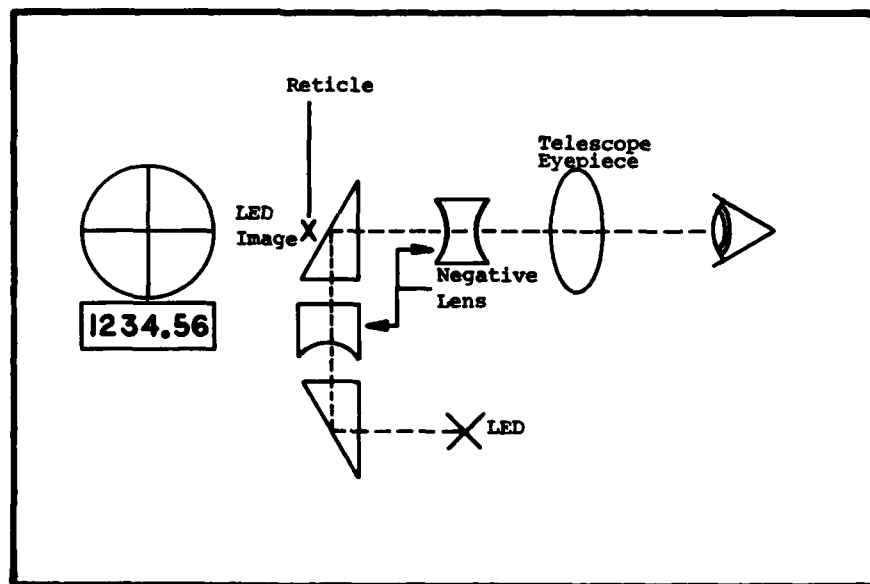


Figure 3. Optical Path Scope Display

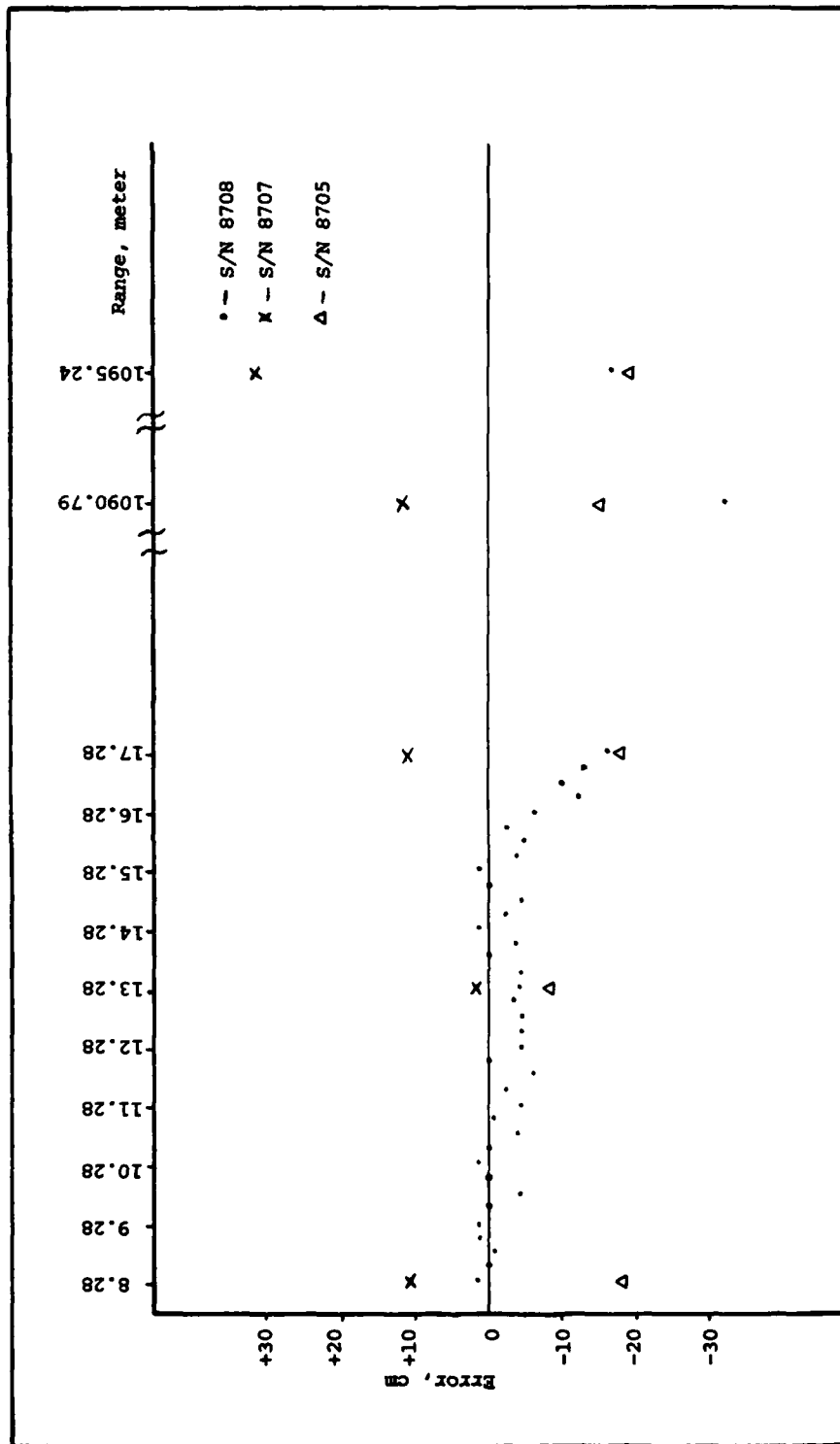


Figure 4. Range Error

## INERTIAL SURVEYING

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## BIOGRAPHICAL SKETCH

John H. Wickham, Jr. has forty-three years of experience in a great variety of surveying and mapping practices, having been associated with State and Federal agencies, active military service, private practicing photogrammetric service companies and firms engaged in design, development, manufacturing, sale and lease of photogrammetric surveying and computer graphic systems. For the last six years he has been a world leader in applying the private practice pursuits of inertial surveying technology and its applications to surveying and geodesy. John is a long standing member of the American Society of Photogrammetry and served ASP as its President for the 1975-1976 term of office.

## ABSTRACT

Technical details of the available Inertial Survey Systems are not covered. The Author advises on the sources of technical and operational papers which treat the subject and he cites examples of inertial survey projects performed by District offices of the Corp. Emphasis is placed on the necessity of thorough and good inertial survey project planning. The plans must encompass multiple projects to realize the full potential of cost savings. Information on the availability of Inertial Survey Systems for contracting is covered.

## INERTIAL SURVEYING

This presentation on Inertial Survey Systems will not encompass the technical aspects of the "spinning" gyros nor their associated "tensioned" accelerometers nor the system computer and its operating software or the human interventions that go to make up an operating Inertial Survey System. These technical matters have been well documented.

I bring to your attention the latest collection of such papers, which treats this new inertial technology for surveying. Proceedings of the Second International Symposium on Inertial Technology for Surveying and Geodesy, held in Banff, Canada in June 1981 are available through the Canadian Institute of Surveyors. During August 1981 the International Federation of Surveyors (FIG) convened. Commission 5's Study Group developed a program on Doppler and Inertial Systems. These proceedings are published and available through FIG. The Seventh Edition of the text book Surveying, by Francis H. Moffit is now available through school book stores. To my knowledge this is the first school text to include a chapter on inertial surveying. Obtain, read and digest these documents and with inertial operating experience you will be approaching par of my six or so years of close association and use of inertial survey systems and their practices.

Yes, these and other papers will introduce or, as the case may be, further inform and bring you current on this new tool for your survey use considerations. You are placed in an even more enviable position to seek knowledge of how inertial technology can aide you in tasks of survey, for you have an in-house fountain of information and knowledge on the subject. This source is no other than Mr. Ed Roof of your own US Army Engineer Topographic Laboratories and the Chairman of this Session 7. You may or may not know, but it was through the wisdom and funds of ETL and the Defense Mapping Agency that today you do have an option to use inertial technology for your survey practices. Ed, thanks to you for your personal efforts.

The currently used practical applications of inertial surveying will greatly aide you in your civil works programs. The down stream wishful or blue-sky projections are great to anticipate and possibly to plan for use of this innovative new surveying technology, but you need not. Just rely on the accomplished and practical works of inertial surveying and reap the rewards. No, the use of inertial survey technology will not accomplish all tasks of survey required by you surveyors, but I can more than assure you that inertial surveying will provide the means to accomplish many tasks and if correctly employed, planned and executed properly will be more effective and efficient over previously used methods of survey. You must also recognize that inertial surveying provides you the means for innovating and accomplishing a survey or gathering massive amounts of terrain data which is just about impossible to do by methods of survey which you are probably now employing. This fact alone demands that you not take inertial surveying lightly during your phase of project planning -- consider and employ it's use!

Inertial survey was considered and employed by at least three District offices, the Portland, Huntington, and Louisville Districts. Some of you are probably aware of these inertial survey works, but a recap is probably in order.

The Portland District was the first Corp District to use a commercially available Inertial Survey System. Their project surveyor considered and used inertial survey to extend X, Y & Z control from a NGS 1st Order control net to 400 photo-identifiable points for aerial triangulation purposes. During the traverse to these 400 points, additional one minute stops were made to provide coordinates for the start point of conventional field survey profiles for flood plane studies. Planning by the Corp's surveyors also availed themselves of the systems use while on location to switch from a land vehicle traverse to a helicopter traverse coordinating 160 monumented section corners.

The Huntington District traversed, 1,500 miles by inertial survey methods. This extended and densified horizontal and vertical control from NGS stations and acceptable vertical benches to 81 monumented stations around existing water reservoirs. Pairs of the monumented stations were inter-visible for azimuth needs of future local surveys.

The Louisville District established horizontal and vertical stations for subsequent photogrammetric mapping.

These and possible other projects done by the Corp of Engineers, through the services of the ETL's or contracted systems, hopefully have more than demonstrated the desirable usefulness of inertial survey for the Civil Works of the Corp. This usefulness is in my opinion the "tip of the iceberg". With experience and continuing development of the Inertial Survey System, accuracies and reliabilities are increasing while a wider range of survey applications have and will continue to emerge. The projects I have cited were hopefully cost savings to the Corp. Yet, I would suspect that the saving was marginal or to put it in another frame of reference -- not the cost savings which could have occurred. This is not to say that the individual projects were inefficient in planning and execution. Rather, it was that the survey requirements were modest in volume of data acquired. The Portland District's inertial project began to approach a real pay off of cost savings. On bringing the inertial system in, three distinct survey needs were planned, executed and fulfilled. I cite this, for in it lies the extremely clear answer of how to really create and realize a cost savings on some of your survey practices. Simply put, alter our survey project planning to accomplish within and between your Districts, a number of different survey projects. Through this planning, the volume of data to be acquired works hand and glove toward realizing the high cost savings benefits inertial surveying can afford you. Yes, it is more simply said than done, but not an impossible task. In fact, the task will be very pleasant, for who in their right mind doesn't need or want to save the dollar and at the same time receive an equal or better product?

Of the numerous inertial navigation systems in use today on high performance aircrafts and various weapons systems three have undergone further design and development producing Inertial Survey Systems. Litton Guidance and Control produced their PADS (Position and Azimuth Determining System) and the Autosurveyor<sup>TM</sup>. With further system tailoring the Autosurveyor appears as the ISS (Inertial Survey System); the IPS-1 (Inertial Positioning System #1); and the SPANMARK<sup>TM</sup>. Ferranti's inertial navigation system emerged for the British Military as the PADS (Position and Azimuth Determining System) then as the FILS-I and FILS-II<sup>TM</sup> (Ferranti Inertial Land Surveyor). Honeywell's SPIN-GINS<sup>TM</sup> inertial navigation system developed into the GEO-SPIN<sup>TM</sup> which is referred to by the Defense Mapping Agency as the IPS-2 (Inertial Positioning System #2).

These three basic manufactured Inertial Surveying Systems now comprise some twenty or more operating systems for governmental or private practice use. Their varying hardware, software and operational techniques differ to produce the system's end product, geographical X, Y & Z coordinates and gravity data. Further off-line data processing occurs for data analysis and accuracy refinement and formatting for client and data entry for computer batch processing needs. Gentlemen, inertially derived survey data is not labor intensive, it's automated to the hilt, the coordinate data required no further computations of the client and the system's data is directly computer addressable. This fact as coupled with the



speed of traverse to acquire the data are the ingredients which make up for an extremely low cost per point of data on projects properly planned for justifying the inertial application of survey. The IBM coinage of words "Plan Ahead" is surely appropriate for inertial surveying.

The primary source for you to obtain use of an Inertial Survey System or a service thereof is your own ETL, SPAN International of Scottsdale, Arizona; SHELTECH, Ltd. of Calgary, Alberta Canada and Houston, Texas or my company, WORLD SURVEYS, INCORPORATED of Cape Canaveral, Florida. Contracting for the inertial survey function differs between companies, but hopefully is structured to your requirements and best interests. Possibly down the road you may plunge and purchase a system, gulping along the way.

WORLD SURVEYS, INCORPORATED is financially and technically associated with the Odom companies of Baton Rouge, Louisiana, but is managed and operated with complete autonomy. WSI offers to the Corp a professional surveying service. We select and use the most modern and proven positioning systems available whether it be ranging, Doppler satellite, or inertial systems. The tool or tools to best accomplish a survey objective is planned in cooperation with other Survey or Engineering firms. It is through the service of the Survey or Engineering firms that WSI's service is provided to the Corp.

The arsenal of positioning systems available to WSI will soon include, but not limited to, the second generation Inertial Survey System, the Honeywell GEO-SPIN. With the GEO-SPIN, WSI very confidently expects to produce high density grid surveys to horizontal Second Order, Class II accuracies at  $\frac{1}{4}$  mile spacing intervals. Verticals will be at low-centimeter accuracies. Down stream, but soon, WSI will be profiling with a helicopter borne inertial system employing a system integrated pulsed GaAs (gallium arsenide) laser for vertical ranging. These and other potentials afforded by inertial technology to surveying can be considered as wishful thinking or blue-sky projections, but if practical end objectives are kept foremost in mind during the development of such applications then a company such as WSI prevails and pursues, for WSI and you, the surveyor, will join in the positive benefits.

SESSION VIII: AIRBORNE LASERS



Ed Link  
WES  
Chairman

*Speakers*



Walt Senus  
DMA



Bill Chapman  
USGS



Bill Krabill  
NASA



Philip Bailey  
WES  
(No Paper)

SESSION VIII  
AIRBORNE LASERS

Summary

Session VIII provided a review of airborne laser systems, including two systems under development (the Defense Mapping Agency Hydrographic Airborne Laser Sounder and the U. S. Geological Survey Aerial Profiling of Terrain System) and two systems currently operating (the NASA Airborne Oceanographic Lidar and the AVCO-Everett, Inc., Airborne Laser Profiling System). The operating systems provide a capability for both terrain and bathymetric elevation mapping that appears compatible with many Corps planning activities. The systems under development demonstrate the commitment of other government agencies to the large-scale application of airborne laser mapping technology. Advancements in laser and positioning system technology can provide systems capable of the accuracies required for Corps survey and design studies where elevation data are required over large areas. The Corps should attempt prototype or test case studies to further evaluate this technology.

## THE HYDROGRAPHIC AIRBORNE LASER SOUNDER (HALS)

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### BIOGRAPHICAL SKETCH

Stephen M. Webb is a Physical Scientist with the Systems and Techniques Directorate, Advanced Technology Division of the Headquarters, Defense Mapping Agency. He obtained his B.S. degree in geology from Oregon State University in 1964. He has worked for the Aeronautical Chart and Information Center as a photogrammetrist and the Naval Oceanographic Office as an oceanographer before coming to DMA. His present duties include assisting in the management of research and development programs pertaining to hydrographic data collection.

### ABSTRACT

To provide an increase in hydrographic survey resources the Hydrographic Airborne Laser Sounder is being developed by the Naval Ocean Research and Development Activity (NORDA) under the sponsorship of the Defense Mapping Agency (DMA). The HALS system incorporates a pulsed, scanning blue-green laser and will be flown in a helicopter from a survey ship operated by the U.S. Naval Oceanographic Office (NAVOCEANO). Through the use of statistics in post-flight processing the HALS data will meet survey accuracy standards, more than adequate for safe navigation. NORDA will perform a technical evaluation of HALS and then turn the system over to NAVOCEANO for operation in late 1983.

### INTRODUCTION

There is serious concern in the international hydrographic community that existing survey resources are too limited to perform the detailed broad area surveys required for new chart editions to be produced in the 1980s and beyond. While state-of-the-art hydrographic surveying methods and systems result in accurate depiction of the ocean floor, there is a great need to drastically increase the data collection rate and cost effectiveness of survey operations.

The Defense Mapping Agency (DMA) has been investigating a number of new charting tools, and their associated cost efficiency, that may provide a partial solution to the above dilemma. Hydrographic data collection technologies involving remote sensors and electro-optical techniques provide the greatest potential for collecting large amounts of hydrographic data very rapidly over shallow coastal waters. Remote areas that are too costly to reach by survey ships or otherwise inaccessible would be prime targets for exploitation of these new systems.

One remote sensing system now under development by the Naval Ocean Research and Development Activity (NORDA) under the sponsorship of DMA is the Hydrographic Airborne Laser Sounder (HALS) System. As can be seen from the HALS performance requirements in Table 1 the system will gather large amounts of hydrographic data in a short time. HALS is expected to increase a survey ship's productivity by 30%.

## HALS SYSTEM

The HALS system is an airborne laser bathymeter consisting of a scanning beam pulsed laser which measures water depth. As the laser energy emitted from the system strikes the water surface, part of it reflects off the surface and part is transmitted through the water column to the bottom. If the water is not too deep or too turbid, some of the light reflects from the bottom and a receiver in the aircraft detects the reflected light and measures the time delay between the surface and bottom reflections (Figure 1). This time delay is then used to compute water depth. Depending on conditions of water clarity, the HALS will be able to measure depths from a minimum of .5 meters to a maximum of 50 meters.

Hardware. The major components of the HALS assembly include a laser transmitter, scanner, receiver, preprocessor, orientation sensing device, clock, horizontal positioning system and recorder (Figure 2).

The HALS laser transmitter is a frequency doubled neodymium doped yttrium-aluminum-garnet laser (Nd:YAG) transmitting at a wavelength of 530 nanometers. This wavelength is optimal for penetration of most coastal water types. The pulse repetition rate is 400 hertz with a pulse width of approximately 5 nanoseconds. These specific performance requirements for the laser were chosen to maximize the signal to noise ratio and resolution of shallow water depths.

The HALS scanner assembly consists principally of a rotating mirror with a constant rotation rate (Figure 3). The elliptical scan pattern which results provides both the necessary data coverage and a means of determining the aircraft attitude.

The horizontal positioning system used by HALS will be the Cubic Western ARG0 Model DM-54 medium range system. In addition, the HALS will be compatible with, and an interface provided for, the Del Norte "Flying Flagman" short range positioning system. The short range system will be used for surveys made at scales of 1/25,000 or larger. In order to determine the horizontal placement of each sounding, the aircraft pitch, roll, heading and scanner orientation is recorded at the instant the sounding is made.

Data Processing. NORDA has the responsibility to develop the HALS postprocessing software. Actual depth soundings and horizontal placement of the soundings will be accomplished during post-mission data processing. Several types of data will be made available by the HALS. Individual laser soundings (Figure 4) will be plotted by the postprocessing system. Additionally, the data will be gridded at a selectable grid spacing with depths assigned to grid locations based on all measured depths in the four adjacent grid cells. The gridding will be accomplished by a two dimensional optimal filter which will deal with both depth and horizontal position errors simultaneously. The purpose of this gridding is to reduce sounding density and improve data quality to ensure its adequacy for safe navigation. Shallower depths and soundings depths closer to grid intersections will be weighted more heavily in determining depth values for the grid location, thus providing in a deliberate conservative bias toward the shallow depths.

Data quality parameters will be computed for each gridded value, permitting evaluation by the hydrographer of overall data quality. Areas that show poor data quality would be scheduled for resurvey with the HALS at increased data density by reducing scan rate, flight speed and/or altitude. An interactive ability to edit digital HALS data and merge it with digital data collected by the survey ship and launches is being developed concurrently.

## OPERATIONS

Operational deployment of the HALS is scheduled for 1983 in the SH-2D helicopter (Figure 5) attached to the coastal survey vessel USNS HARKNESS. The system will be flown at altitudes from 150 to 1000 meters and speeds from 0 to 60 meters per second. The scan angle will be variable from 0 to 25 degrees and will, along with flight speed and altitude, be used to determine the data density. Average density will be at least one sounding per 20 square meters, with increased coverage required for larger scale surveys. There will be three operational types of HALS missions: cross-check lines, principal survey lines, and saturation surveys (Figure 6). Cross-check lines will be run perpendicular to the depth contours; principal survey lines will be run nearly parallel to depth contours to maximize their length. Saturation surveys for shoals and hazardous areas will be run at low speed to increase data density.

## HALS DEVELOPMENT SCHEDULE

NORDA prepared the system specifications in 1978. AVCO Everett Research Laboratory (AERL) was selected as the prime HALS contractor in September, 1979. Under the terms of the contract AERL will design, fabricate and test HALS with delivery to NORDA in late 1982. AERL should complete system integration by 1 March and environmental test by mid-May 1982. Following field acceptance tests which AERL estimates will be finished by 1 October, NORDA will conduct an intensive technical evaluation lasting from six to twelve months. At the conclusion of this technical evaluation NAVOCEANO will run operational evaluations and then start survey operation in late 1983. As soon as the NAVSTAR Global Positioning System (GPS) becomes available, about 1988, HALS will be deployed in a fixed wing aircraft. A second generation HALS using a high pulse rate (>5000hz) metal vapor laser is projected to be available at about the same time. The result will be an extremely capable survey system.

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TABLE 1

## HALS PERFORMANCE REQUIREMENTS

Altitude	100 to 800 m; 150 m nominal.
Forward Velocity	37 m/s nominal.
Vertical Depth	0.5m to 50m; 20 m required at maximum scan angle for $K^* = 0.16 \text{ m}^{-1}$ ).
Slant Range Measuring Accuracy	
Altitude	$\pm 0.01\text{m}$ or 0.05% of range (larger).
Water Depth	$\pm 0.28\text{M}$ for depth from 0.5 to 20 M; $\pm 1.0$ for depths $> 20 \text{ m}$ .
Area Coverage	One sounding per $20 \text{ m}^2$ (average) at an altitude of 150 m, velocity of 37 m/s and maximum scan angle. Also, one sounding in every circle of 9 m diameter.
Scan Angle	Variable, 0 to 624 mrad.
Sea State	Operation to Beaufort 3 wind conditions.
Solar Angle	Operation at zenith angles $> 46^\circ$
Horizontal Position Accuracy	1.65 sigma value of 1.5 mm times the scale of survey.

\*  $K$  = diffuse optical attenuation coefficient;  $I = I_0 e^{-KZ}$

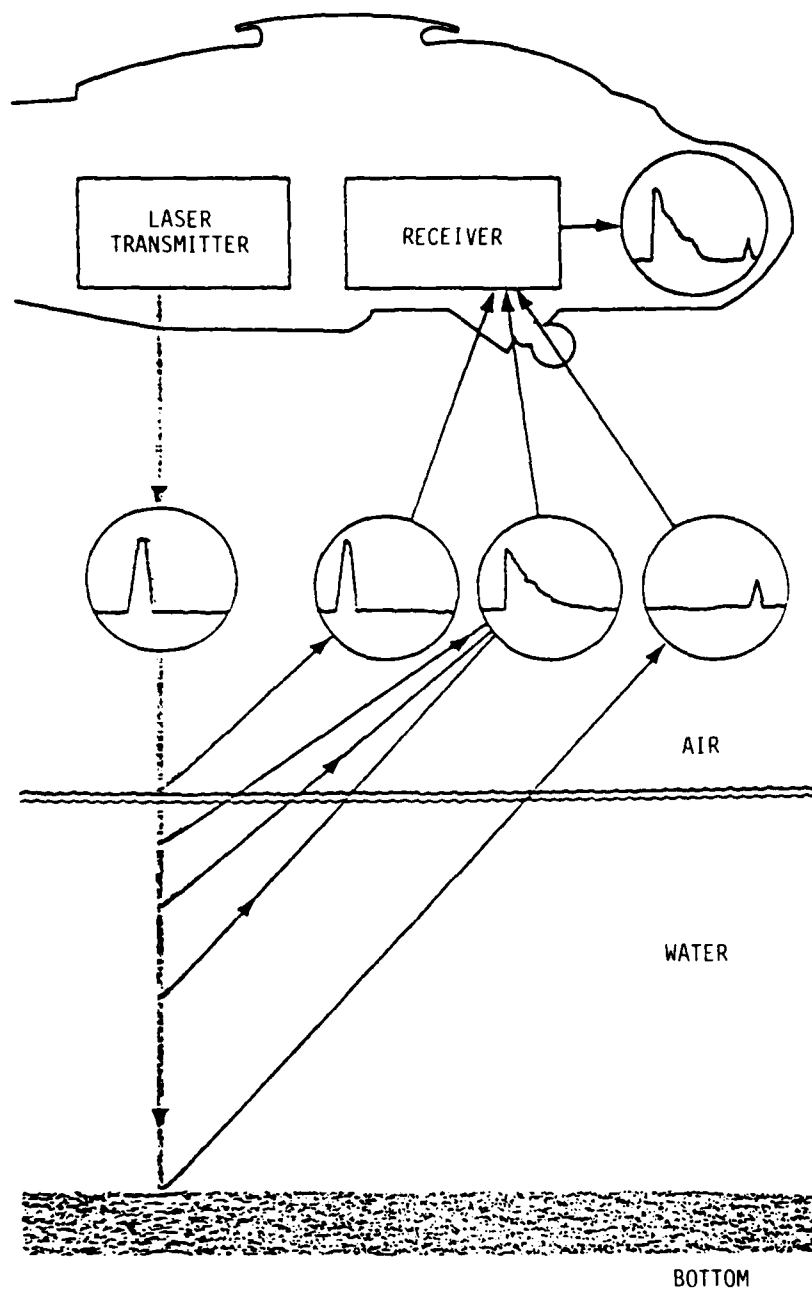


Figure 1. HALS transmitted and return waveforms.



## AIRCRAFT HARDWARE

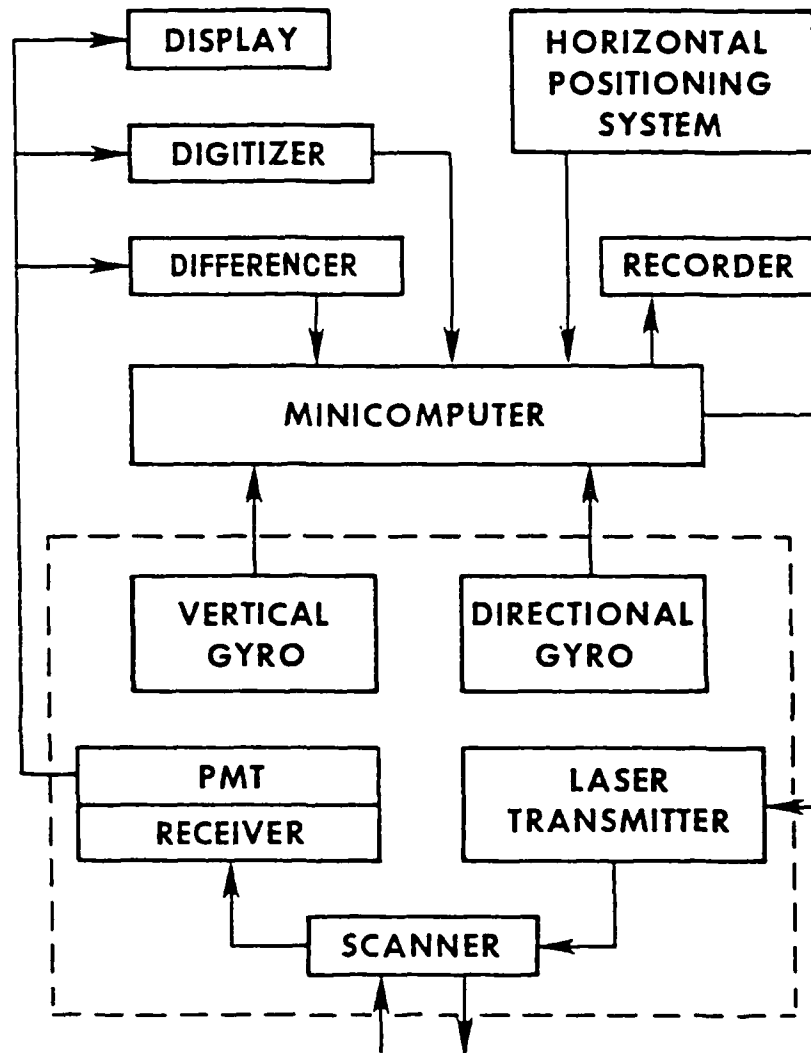
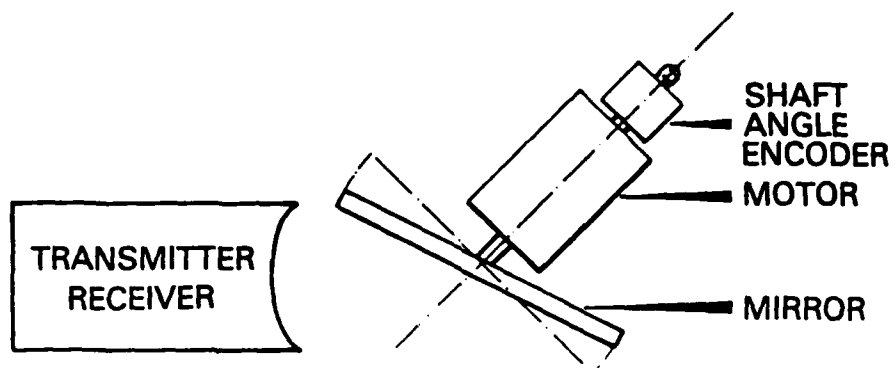


Figure 2. HALS hardware block diagram

## NUTATING MIRROR



## SCAN PATTERN PRODUCED

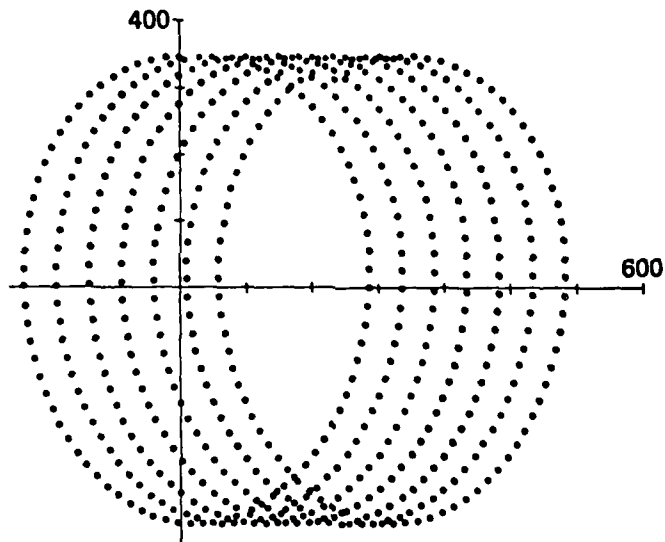


Figure 3. HALS scanner mirror and scan pattern

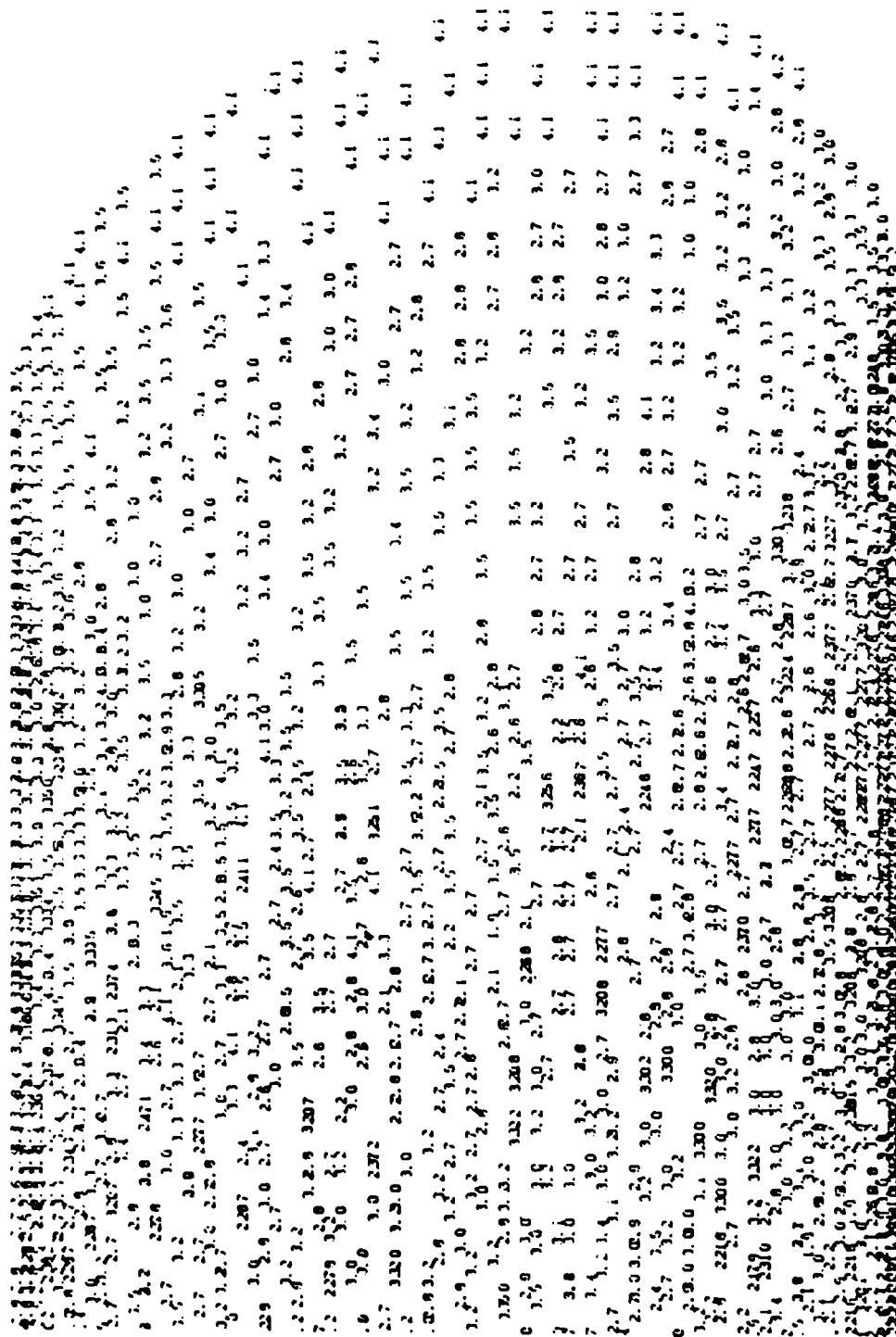


Figure 4. Data printout of HALS swath path

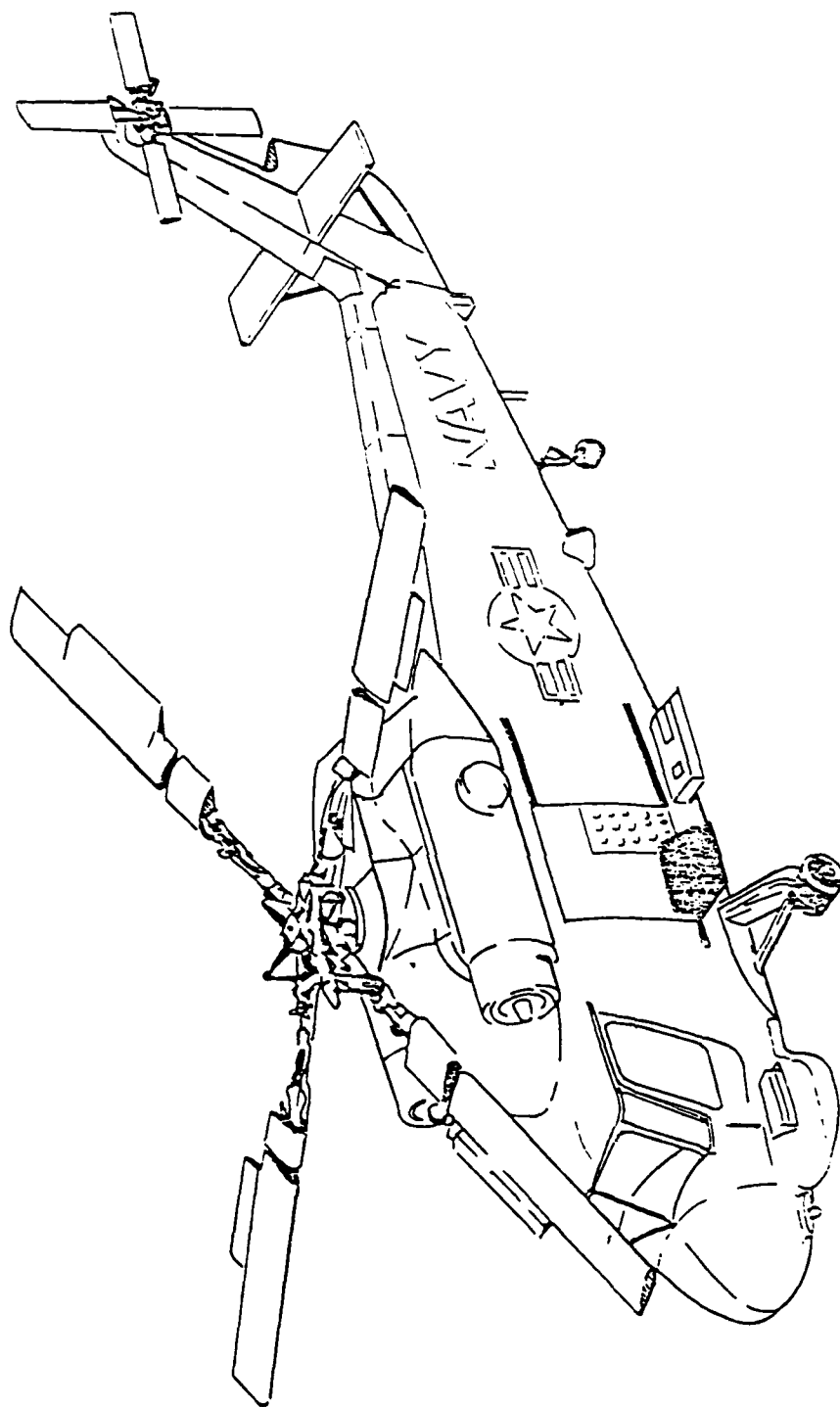


Figure 5. SH-2D helicopter with HALS mounted in doorway

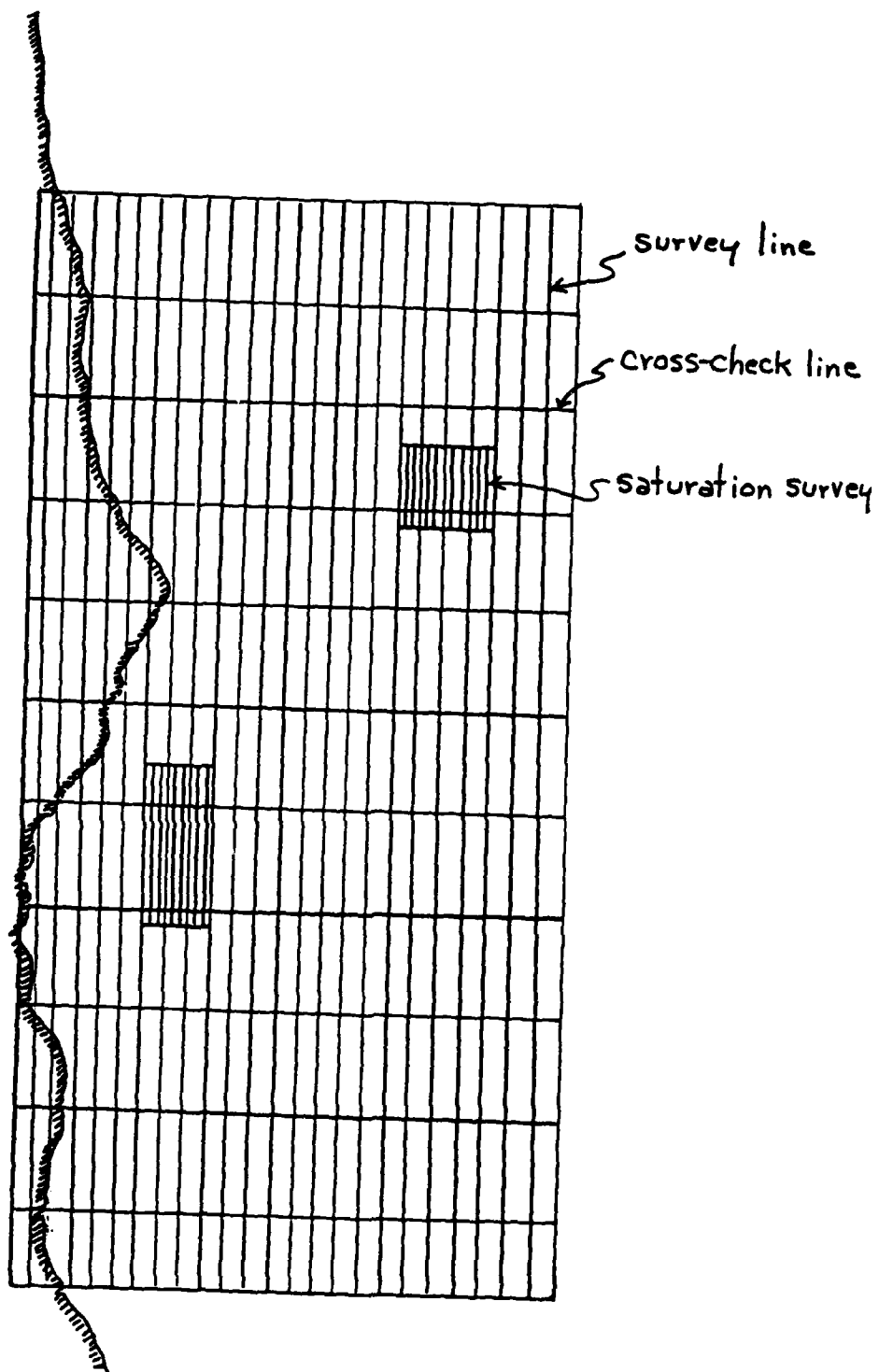


Figure 6. Three types of HALS survey lines

## AERIAL PROFILING OF TERRAIN SYSTEM

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### BIOGRAPHICAL SKETCH

William H. Chapman received a B.S. in civil engineering from the University of California in 1950. He began his career with the U.S. Geological Survey in the Pacific Region, where he specialized in field surveys for obtaining map control. In 1957 he was assigned to the Office of Research and Technical Standards, Topographic Division, in Washington, D.C. In 1966 he received an M.S. in geodesy from Ohio State University. He is a registered professional engineer and a member of the American Society of Civil Engineers.

### ABSTRACT

In 1974 the U.S. Geological Survey entered into an engineering analysis contract with Charles Stark Draper Laboratory to study the concept of executing accurate surveys of the terrain from low-flying aircraft using a laser profiler and inertial guidance technology. This analysis and later studies concluded that the desired accuracy, within 0.5 feet (15 cm) vertically and 2 feet (61 cm) horizontally, could be achieved for extended missions if positional updates are provided at 3-minute time intervals. A laser tracking instrument for ranging and measuring directions to ground reflectors was proposed to provide the update data. The project has progressed through the early experimental phases, system design and component fabrication, and the integration of components into subsystems has begun. Laboratory calibration and testing of the system will be completed in the fall of 1982 and installation in the Twin-Otter<sup>1</sup> aircraft will then begin, and flight testing will follow beginning in early 1983.

### INTRODUCTION

In 1974 U.S. Geological Survey research scientists were considering the development of an airborne instrument for measuring stream-valley cross sections and profiles. These data were needed along many thousand kilometers of streams as an adjunct to streamstage data in defining the extent of floods of various levels. The Survey elected to explore the technical prospects for developing an airborne instrument system containing a laser profiler to

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<sup>1</sup>Any use of trade names and trademarks is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

measure the distance from the aircraft to the terrain and an inertial measuring unit (IMU) to establish and maintain a three-coordinate reference system. Positions of terrain points beneath the moving aircraft would be given by the IMU, and images of the points would be recorded by a film or TV camera. The instrument system would be carried in a relatively light single- or twin-engine airplane at flight heights not more than 900 m (3,000 feet) above the terrain.

During the initial planning, considerable effort was made to involve other organizations having interest in this program. Scientists from Harry Diamond Laboratory were added to the USGS team to provide expertise in laser technology. Liaison was established with cognizant technical personnel in the Defense Mapping Agency, National Aeronautics and Space Administration, National Ocean Survey, and the Flood Insurance Administration to assist in identifying requirements and prior research and development.

A contract was awarded to Charles Stark Draper Laboratory (CSDL) to conduct an engineering analysis of the proposed system. The proposal stated that the absolute positional accuracy of points along terrain profiles should be  $\pm 0.5$  ft (15 cm) vertically and  $\pm 10$  ft (3 m)<sup>2</sup> horizontally at the 90-percent reliability level. Results of the CSDL study, completed in 1975, established that the stated accuracies could be attained using state-of-the-art gyro and accelerometer components if system updating occurred every 3 minutes during data gathering. The recommended updating component was a laser tracking and ranging instrument that would lock onto and track a ground reflector. The tracker would measure range and the directions to the reflector (see Figure 1), with angles referred to the airborne three-coordinate reference system. The conclusions of the engineering analysis led to a series of contracts to design the system, fabricate the system components, and modify an aircraft for accommodating the Aerial Profiling of Terrain System (APTS). Work is now underway to complete laboratory calibration and testing of the system, and flight testing will begin in January 1983.

#### AERIAL PROFILING OF TERRAIN SYSTEM

The APTS airborne instruments include laser profiler (altimeter), a gimbaled three-axis inertial platform, and a two-axis tracker. The tracker measures distances and directions to previously surveyed reflectors to provide update information. The inertial platform and laser tracker constitute the high-accuracy three-coordinate

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<sup>2</sup>This specification was changed in September 1978 from  $\pm 10$  ft (3 m) to  $\pm 2$  ft (61 cm) resulting from further study of system capability.

position datum that enables the measured terrain elevations from the laser profiler to be geodetically referenced.

A schematic of the basic airborne-instrument group--inertial measuring unit (IMU) and laser tracker--is shown in Figure 2. An airborne computer accepts data from these sensors and performs the necessary computations for alignment of the IMU, navigation, and position and velocity updating. In addition, the computer outputs data to the onboard magnetic tape recorder and control/display unit. The data flow between these components are shown in Figure 3.

Internal to the IMU is the stable platform which incorporates three state-of-the-art gyros and three pendulous gyro integrating accelerometers along with their associated electronics. Outside the stable platform are three servo-driven isolation gimbals under control of the gyros. These gimbals (azimuth, elevation, and roll, in that order) isolate the stable platform from aircraft rotation and maintains a constant platform orientation of north, east, and nadir. The support structure surrounding the isolation gimbals is designed so that the tracker assembly mounts directly to its base, thereby providing a physical tie between the stable platform and the tracker pointing axes.

The IMU has a unique thermal control system that isolates the inertial instruments from the outside environment and maintains the gyro and accelerometer mounting surfaces on the stable platform at  $40 \pm 0.05^\circ \text{C}$ . The laser-profiler/vertical-camera assembly is mounted on the same rigid frame as the IMU/tracker. Since the profiler is not held level by gimbals, misalignment of the profiler with respect to the plumb line will be corrected during postmission processing using IMU gimbal angle data.

The profiler and tracker employ pulsed laser ranging techniques that determine distance by measuring the transit time of a transmitted laser pulse. Eye-safe gallium arsenide lasers are used as the transmitters in both devices. Constant-fraction techniques used in the return-signal receivers minimize timing errors due to pulse amplitude variations, and pulse selection techniques used in the profiler maximize the number of valid returns from terrain in the presence of trees or other vegetation. The tracker contains a beam splitter to separate the ranging and tracking functions. A quadrant detector provides the error signals to the gimbal servos of the tracker. A precision timer multiplexed between the profiler and tracker determines the range measurements.

The control and display subsystem enables the operator to sequence the system through its various operating modes and to monitor the status of the system. System characteristics, such as temperatures of inertial and other key components, critical voltages, and operational modes, are displayed on the console.



The IMU, tracker, profiler, and control and display console are not only designed to meet the system performance specifications, but they are designed to operate within the physical and environmental limitations of a relatively light Twin-Otter aircraft. There are separate modules for convenient installation, operation, and servicing within the confines of a small cabin. The proposed arrangement of the instruments in the Twin-Otter are shown in Figure 4.

#### SYSTEM OPERATIONS

A hypothetical mission best describes the operation of the APT system. A local area to be surveyed is 30 km by 30 km, the topography is not mountainous but of foothill type or flatter, and some geodetic control already exists. The product of the APTS survey will be two magnetic tapes, one containing the terrain profile data for the flight paths over the survey and the other containing video imagery of the terrain along the flight paths.

1. An advance ground party will place simple, inexpensive, expendable reflectors in and near the survey area. Reflectors will be placed on three selected basic horizontal and vertical control stations that bracket the survey area. Other reflectors will be placed at selected intermediate locations throughout the area.

2. A flight plan will be drawn on a convenient medium-scale map. The H and V values of each reflector and H value for the beginning and ending points of each desired flight path (terrain profile) will be scaled and listed. This data should be accurate enough for determining the flight paths where profiles are desired and for establishing initial pointing angles to the reflectors for the laser tracker search and lock-on sequence. Also needed are the H and V values for a point at the departure airport for use during premission alinement.

3. Airport locations must be selected that have adequate facilities to support and initialize the system. The system will self-calibrate and orient to the local plumb line and astronomic north. During this phase, the H and V list, a gravity model, and parameters of the reference ellipsoid for the survey area must also be loaded into the computer.

4. After takeoff, the inertial platform will guide the aircraft to the survey area and during the profiling and calibration flight passes. The flight from the local airport to the survey area can last a half hour or more. Long flights are acceptable because an airborne recalibration is done upon reaching the survey area.

5. The first pass or calibration flight over the survey area will be from one presurveyed reflector to a second midway across the area and thence to a third at the far end of the area, followed by a return pass. All

intermediate unsurveyed reflectors within range will be tracked at some time during this round-trip pass and all the measured data stored.

6. When calibration passes are completed, the collection of ground profiles will begin. Each reflector will be automatically tracked when it comes within the tracker field of view, and the resulting tracking data will be recorded and used for determining how well the system is maintaining position, elevation, and orientation (Figure 1).

7. After all profiling is complete, as an initial practice the original calibration line will probably be re-flown to provide data to prorated any changes in the system parameters.

8. After returning to the airport, the magnetic tapes containing the profile data will be subjected to final analysis and postmission processing on an offline computer.

9. After final analysis and postmission processing, editing will be conducted on a viewing console that graphically displays the profile data next to the video image. Abrupt changes on the profile screen will be correlated with the video image to remove any anomaly caused by vegetation or a man-made structure. All profile data will be screened in this manner.

10. After satisfactory adjustment, the profile data will be available for the various planned applications such as establishing control for mapping or for terrain modeling.

#### PROBLEMS

Many research and development activities have problems that are not resolved until the late phases of the program, although they were recognized early in the engineering analysis phase.

One APTS problem concerns the ability of the laser pulse of the profiler to penetrate heavy foliage with sufficient frequency to accurately define the terrain surface. A laboratory model profiler was used to conduct flight tests over various types of vegetation and terrain in September 1976, when foliage was at a maximum, and in April 1977, before new foliage emerged. A small sample of the test data from two different locations is shown in Figures 5 and 6, showing profiler response through a dense stand of deciduous trees at maximum and minimum foliage. The increased density of "hits" (laser reflection from the ground) when the trees are free of foliage is obvious and expected, but the most significant finding is the frequency of hits obtained through heavy foliage during the September pass. The maximum gap between hits is about 12 m. Pulse processing methods are being developed that are more

sophisticated than the simple leading-edge method used in this test, and the number of hits will increase giving better definition of the ground surface.

Another problem that could affect the accuracy of the APT system is caused by irregularities of the Earth's gravitational field. For example:

- o Variations in the force of gravity (gravitational anomalies) will cause large elevation and small position errors if not compensated since the accelerometer can't separate vertical acceleration from gravity changes.
- o Elevation errors will be caused by the difference in the two vertical reference surfaces--the mathematically derived smooth surface maintained by the inertial platform and the undulating surface defined by the local control network, related to the geoid.

The errors caused by gravitational anomalies and the irregularities in the vertical datum (geoidal undulations) are difficult to analyze because detailed gravity information is scarce. The information that is available was generally obtained for geophysical studies and therefore it does not usually exist in the types of country where the system is planned to be used. Since the airborne coordinate system will be related to gravity and geodetic data at the control reflectors, the APT system's mathematical fitting will compensate for bias and regional trends, but not for excursions from a linear fit. An example is given in Figure 7 for an area east of Denver, Colorado, where the gravity anomaly gradient is judged to be typical. Several methods will be tried for correcting the errors due to gravity by:

1. Providing the system with the best available gravity data and if needed, augment this with additional gravity measurements at the surveyed reflectors.
2. Surveying the area in such a manner that the instrument and gravity-caused errors can be separated and adjusted. Flights both directions along a line could help since the instrument errors are a function of time, and gravity-caused errors are a function of location.
3. Reducing reflector spacing to where linear interpolation will produce an acceptable level of errors. This is the only practical method available to control errors resulting from the undulating geoid.

Early in the APTS program, a statistical model was developed to simulate the performance of the APTS during a typical

survey mission. This model was implemented as a computer program, called the truth model, and was somewhat primitive in the beginning. It accounted for only the major sources of errors in the system. The truth model was expanded as the APTS development continued to include more and more sources of errors and further improved by incorporating more accurate estimates of the errors contributed by each instrument. The truth model is now very sophisticated and probably produces a reliable estimate of the accuracy of the total performance of the APTS instruments.

The results of a recent run of the truth model is given in Figure 8. The major error sources are the gravity disturbance and undulation of the geoid, which were discussed previously, and the observability of Kalman Filter states. The last error represents the uncertainty in the final adjustment. These error estimates indicate that the APTS system will meet the accuracy goals and the system's performance is sensitive to unmodeled irregularities in the gravity field. It also points out the possibility of using the APTS for establishing gravity models.

#### CONCLUSIONS

Nearly all data collected by remote sensors must be referenced to a coordinate system before they become of value to most users. This paper has stressed the use of the APT system for collecting terrain profile data for use in various USGS resource analysis and mapping programs. Perhaps of greater significance than this specific application is the inertial technology associated with this system and the capability it offers as a precise three-coordinate reference platform for guiding one of many remote sensors that are commonly used today. The aircraft could easily be fitted with an aerial camera, side-looking radar, magnetometer, infrared scanner, etc., and the IMU-tracker system will provide precise x,y,z coordinates for the focal point of the sensor. Reference data of this precision have great potential for increasing the utility of a number of sensors and would reduce the data-reduction requirements associated with nearly all sensors.

The final phase of APTS prototype development began in December 1981. This 1 1/2-year effort will include the system integration, laboratory testing, shakedown flights, and extensive calibration flights. Test site planning has begun and a 10 x 30 km test area in Massachusetts is being investigated. The site consists of a scattering of small surveyed areas where natural ground patterns are available. Parking lots surrounding shopping centers or office buildings will be used and large-scale orthophoto image maps (1-foot contour interval) will be obtained over each surveyed area. These will provide the fine-detail high-accuracy data needed to test the system's profile output.

After the operational characteristics have been determined by the calibration flights, a 2-year series of application tests will begin. These tests will center on three general types of applications: (1) topographic profiling, including that which originally inspired the APTS effort, flood-plain mapping; (2) sensor control, providing positional information for other sensors, such as aerial cameras, infrared scanners, and magnetometers; and (3) new geodetic surveying and gravity modeling.

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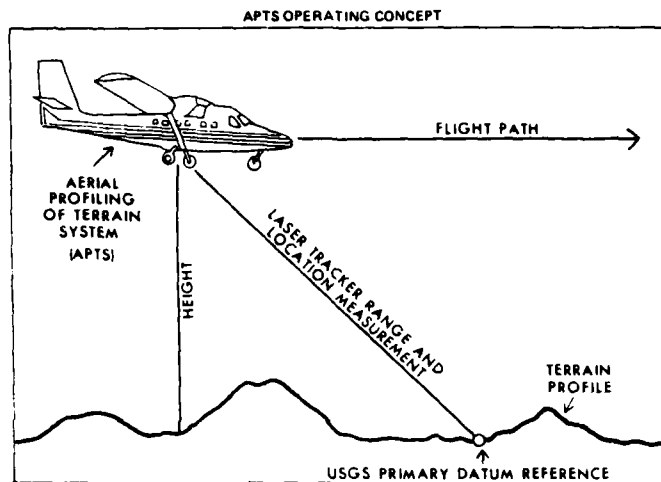


Figure 1.

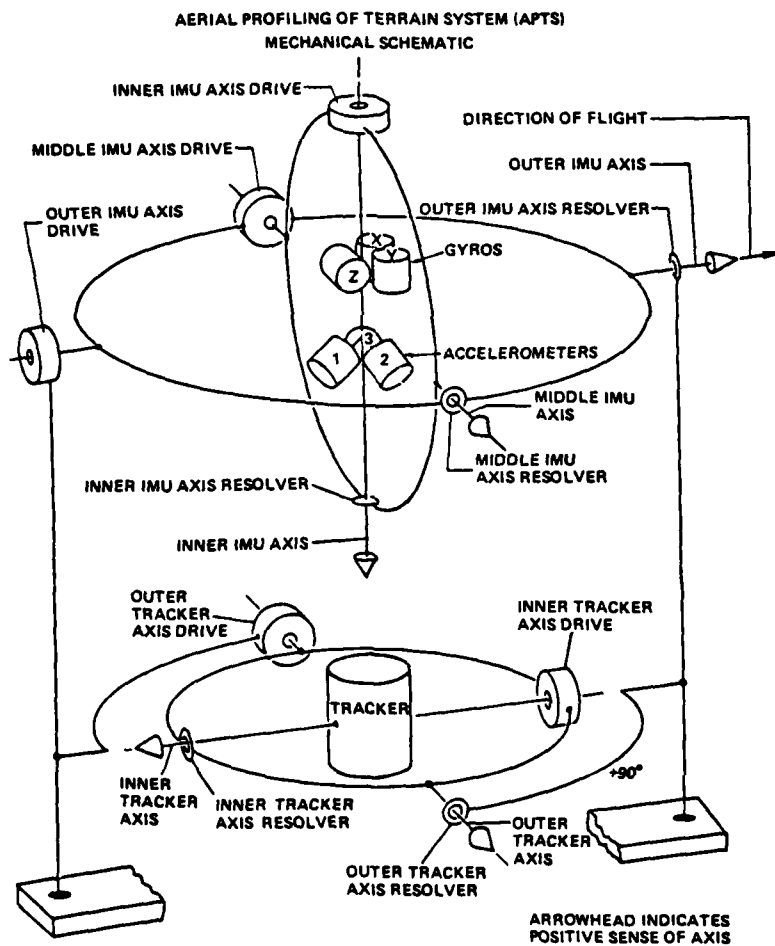
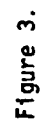
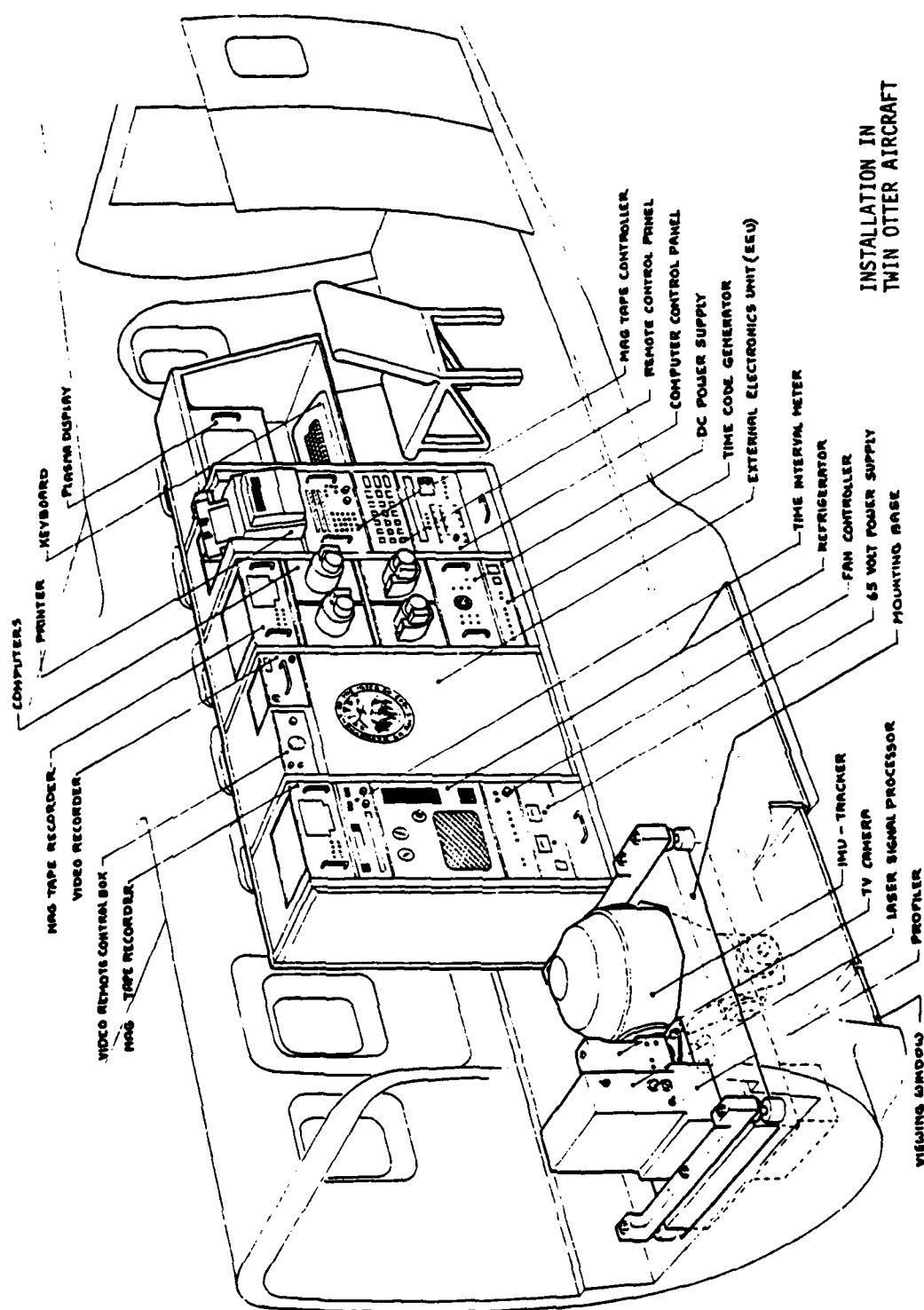


Figure 2.

115499  
UPDATE LOOP  
NAVIGATION  
TRACER SEVING LOOP  
NEW STABILIZATION LOOP  
ATTITUDE STABILIZATION  
ATTITUDE DATA



# AERIAL PROFILING OF TERRAIN SYSTEM (APTS)



INSTALLATION IN  
TWIN OTTER AIRCRAFT

Figure 4.



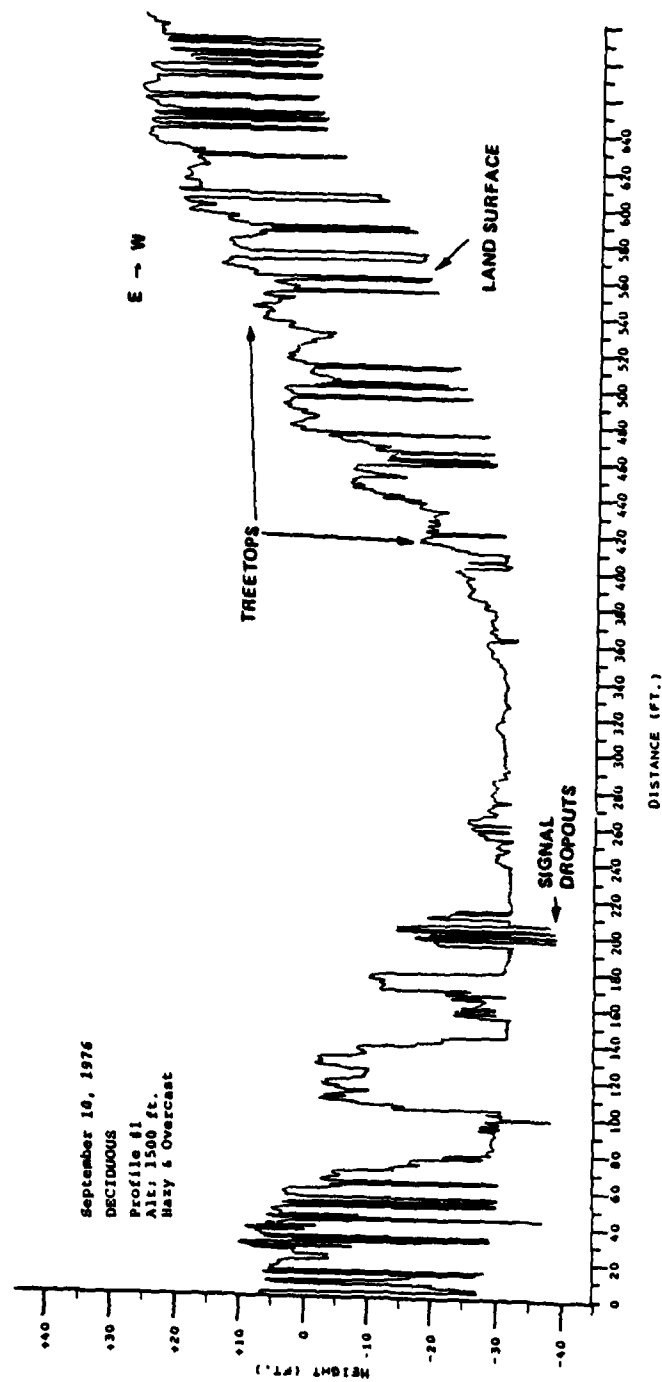


Figure 5. APTS PROFILE - FULL FOLIAGE

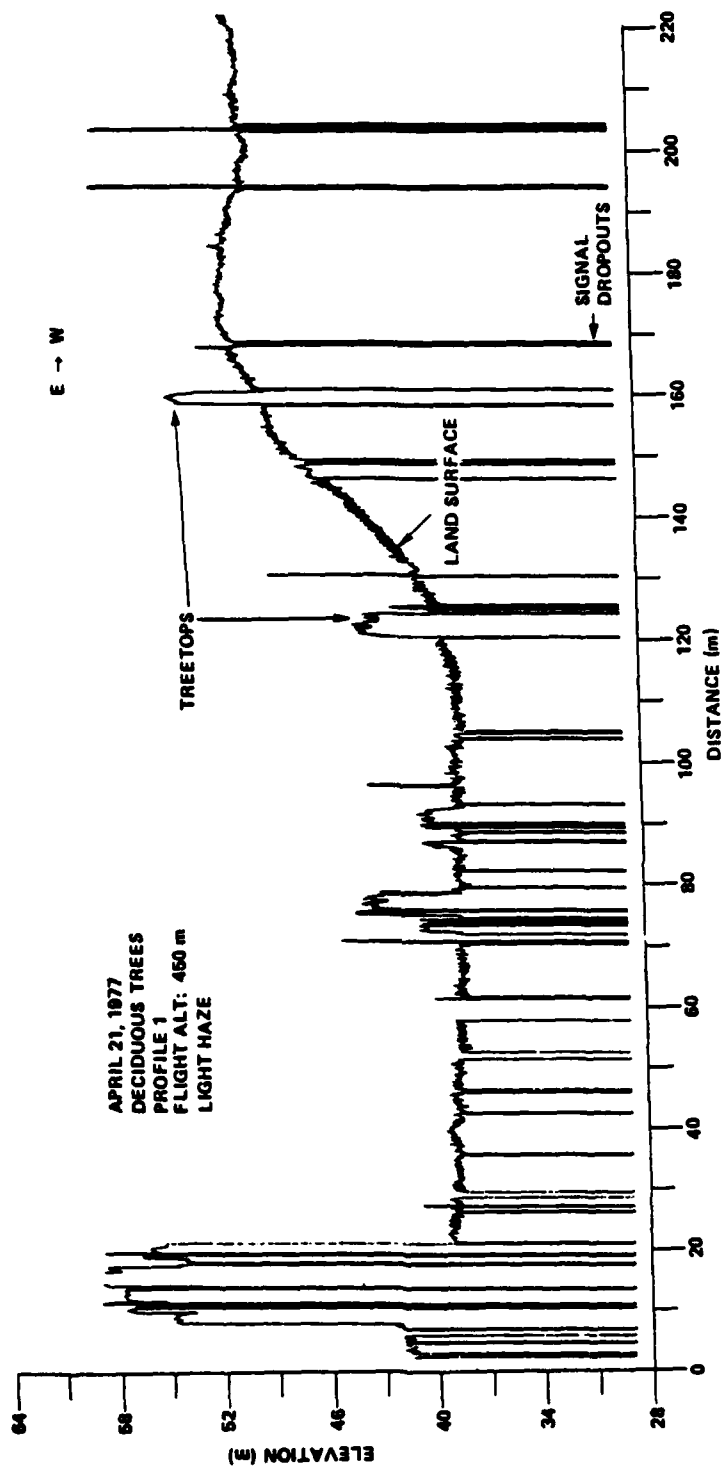


Figure 6. APTS PROFILE - NO FOLIAGE

# TYPICAL CASE OF GRAVITY ANOMALIES AND DEFLECTIONS - DENVER

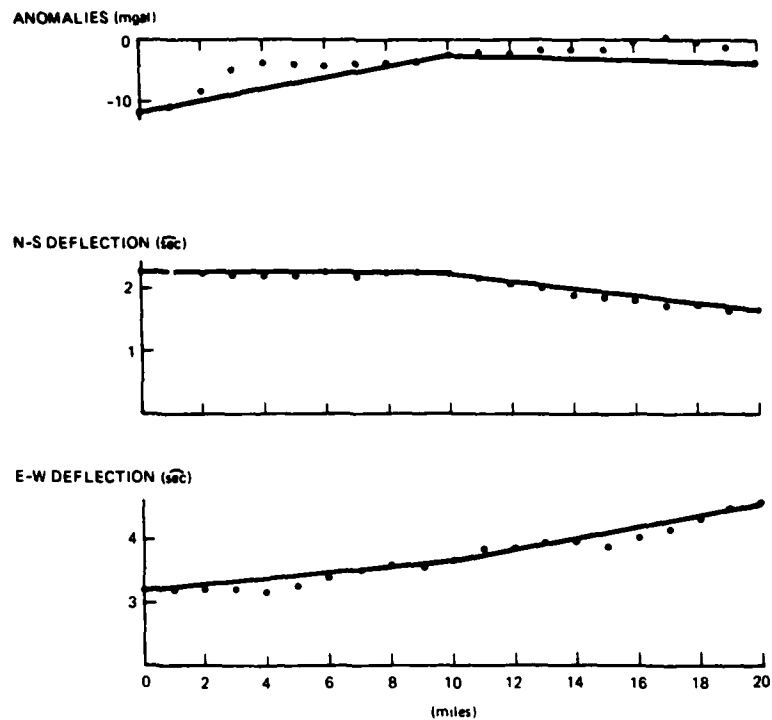


Figure 7.

## APTS ERROR BUDGET

Source	Vertical (cm)	Horizontal (cm)
APTS IMU and Tracker	2.7	10.8
Gravity Disturbance	11.0	44.0
Raybending Estimation Error	3.0	3.0
Vibration	1.0	20.0
Observability of Kalman Filter States	7.1	28.4
Undulation of the Geoid	5.7	0.0
Profiler Subsystem Errors	<u>2.0</u>	<u>18.2</u>
RMS All Sources	15.0	60.0

UPPER LEVEL APTS ERROR BUDGET (90% CONFIDENCE  
NUMBERS = 1.65  $\sigma$ ).

Figure 8.

PRELIMINARY RESULTS OF SHORELINE MAPPING INVESTIGATIONS  
CONDUCTED AT WRIGHTSVILLE BEACH, NC

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BIOGRAPHICAL SKETCHES

William B. Krabill received a B.S. in mathematics from Salisbury State College in 1968. He is currently a staff scientist at NASA's Wallops Flight Center, where he has over 14 years experience as a data analyst and project-scientist. Mr. Krabill is currently the project leader for the development of topographic mapping techniques, utilizing both airborne and satellite instrumentation.

Robert N. Swift received a Masters Degree in Earth and Space Science from Millersville State College (PA). Since graduation in 1970 he has worked as a marine geologist on a number of coastal and off-shore projects. He has been a full time analyst on the Airborne Oceanographic Lidar since 1977.

ABSTRACT

Preliminary results from the joint NASA/COE airborne laser bathymetry experiments conducted over Wrightsville Beach, North Carolina in June 1981 are presented. Brief discussions of the experiment objectives and a description of the field work are given. These missions were flown using a relatively weak neon laser, therefore the analytical results in this paper center on data obtained at night under low light conditions. Profiling passes made normal to the beach and extending over Banks Channel behind Wrightsville Beach are shown in figures and are compared to available truth data acquired with conventional techniques.

These figures present detailed profiles of the positive beach features as well as the submerged bottom adjacent to the shoreline. Penetration to a depth of ~5 m was obtained on most passes. Deeper penetration was precluded by a hardware failure during the experiment. Additional figures are provided to document scanning passes flown over the beach/water interface covering a swath of ~150 m.

Several problems related to shoreline mapping applications for an airborne lidar system are discussed. Newly developed software techniques for processing the return laser waveform appear to have resolved problems related to the recognition of pulses striking land and water targets and appear to have removed surface wave effects from the hydrographic record. The remaining problems in the experimental data involve a requirement for additional laser power and separation of convolved surface and bottom returns in laser records obtained over water depths shoaler than 1 m.

## INTRODUCTION

This report is intended to convey some preliminary results from shoreline mapping investigations conducted over Wrightsville Beach, North Carolina utilizing the WFC Airborne Oceanographic Lidar (AOL). Included is a brief discussion of the experiment objectives as well as a description of the experiment and preliminary results. An expanded treatment of these aspects as well as problems, limitations, and recommendations will be prepared following the final phase of analysis. Further, this paper is limited to results obtained during the mission flown at night under low background light conditions.

These shoreline mapping investigations were conducted as part of a cooperative program between NASA Wallops Flight Center (WFC) and the U.S. Army Corps of Engineers (COE) Wilmington District (North Carolina). The purpose of this program was to gauge the feasibility of utilizing an airborne lidar system to meet certain data requirements of COE in coastal regions. Primary aspects included the acquisition of detailed profile data on open coastlines and gathering detailed hydrographic data in coastal waterways. The beach profiling lines required measurement of both positive and submerged relief across the beach/water interface along lines oriented normal to the trend of the beach. A secondary aspect called for an assessment of airborne lidar swath scanning for meeting these COE data requirements.

Previous experiments in laser hydrography were conducted in a joint NASA/NOAA/NORDA project (Hoge et al, 1980) aimed at evaluating the feasibility of utilizing an airborne lidar system for meeting the bathymetric data requirements of the latter two agencies. These tests were deemed successful and following subsequent analysis of the data sets a decision was made by both agencies to build operational models. The Navy airborne lidar system referred to as the Hydrographic Airborne Laser Sounder (HALS) (Houck, 1980) is currently being built and initial field tests should be conducted in FY82. The NOAA system (Guenther et al, 1978) has been tentatively approved pending available funds. The present hydrographic effort described in this memo differs substantially from the earlier NASA/NOAA/NORDA investigations in that the work with COE was conducted in the highly dynamic nearshore zone with attendant waves, foam, and turbidity. In addition, the earlier work did not include any attempt to extract bathymetric data from water shoaler than 2 m and no elevational data was analyzed over the positive shoreline. Nonetheless many of the analytical techniques previously developed (Swift et al, 1980) were applicable after revision. New algorithm development centered on the formulation of software (1) to extract bottom information from waveforms taken in the highly turbid surf zone, (2) to determine depths in water shoaler than 2 m, (3) to include the total range vector into the bathymetric solution in order to minimize errors in bathymetry due to the presence of waves, and (4) to recognize laser return signatures in order to differentiate pulses striking land targets from pulses striking water targets. The latter software is essential to the processing of any scanning data taken over the beach/water interface.

A number of analytical techniques developed for terrain mapping applications of the AOL (Krabill et al, 1980) in a joint NASA/COE flood plain mapping program (1979-1980) were utilized in processing the recent Wrightsville Beach data. These included software to remove aircraft vertical motion as well as software designed for the treatment of scanning data and the preparation of digital terrain models. The

removal of aircraft vertical motion utilizes information recorded from an inexpensive accelerometer (Krabill *et al.*, 1982) and is extremely critical to our method for removing wave related errors from the near-shore bathymetry data.

#### EXPERIMENT DESCRIPTION

The AOL was flown onboard the WFC P-3 aircraft on separate day and night missions on June 3, 1981. The data from the day mission is currently undergoing preliminary analysis and is not included here. Figure 1 indicates the nonscanning passes while the approximate coverage of the scanning passes is shown in Figure 9. Navigation on the night mission was accomplished with the aid of strobe beacons positioned by ground crews. The computer drawn lines in the above figures were derived from the LTN-51 inertial navigation system without any external correction, consequently they may be slightly in error. As indicated on Figure 1 the profiling passes (2-5) flown over Wrightsville Beach were occupied twice.

A complete description of the AOL system in the bathymetry configuration is given in (Hoge *et al.*, 1980). Pertinent information on the system settings and configuration used in these experiments are discussed briefly below.

An AVCO C-5000 nitrogen laser was filled with neon gas for this mission to provide 7 ns blue-green pulses at 540.1 nm. All passes were taken at a 400 pps rate (the current limit of the system). The AOL system was operated with a 3 mrad beam divergence, a 20 mrad FOV, and with no narrowband filter in place in front of the bathymetry photomultiplier tube. During the missions flown under daylight conditions a narrowband interference filter centered on 540.1 nm was used to reject unwanted ambient light from the PMT and the FOV was adjusted to 10 mrad. The AOL was thoroughly checked and calibrated prior to the mission. Unfortunately, one of the L-161 waveform fan-out modules failed on the first pass. As a result no information was recorded from digitizer channels 10 and 11 (a total of 36 are currently available). A decision was therefore made to increase the delay so that the surface return fell beyond the dead channels into channels 12-16, effectively reducing the temporal sampling capability to 5.5 m or 18 feet instead of the normal 8.8 m or 29 feet. This temporary restriction is not considered to have seriously affected the experiment since deeper water bathymetry was not a prime objective and had been previously demonstrated in the NASA/NOAA/NORDA program.

#### DATA DESCRIPTION

Figure 1 is a map of the Wrightsville Beach, North Carolina area, superimposed with the ground tracks of the profile passes from the night mission. Figures 2-5 display data from some of the passes shown in Figure 1. These figures (flightlines 4 and 5) display typical surface/subsurface profile data from the AOL. The elevations have been adjusted to mean sea level. The data have been edited, smoothed, and, in the case of the bathymetry, corrected for ocean surface waves. The smoothing was accomplished with a simple 11 point moving average filter. With the sampling rate of 400 pulses per second, and an aircraft velocity of approximately 100 meters/second, this amounts to a spatial filter of 2.75 meters (~9 feet).

Superimposed on the profile lines are survey data taken by COE Wilmington District during the week preceding the airborne experiment. As

can be seen on the figures, the COE surface truth data are directly compared to the AOL profile data over the positive beach area. However, the bathymetric portions of the AOL and COE profiles are not overlapping, but are essentially complementary in that the COE profiles begin at approximately 5 m and extend seaward. The original mission planning called for AOL penetration to an additional 3-4 m in depth, however the previously mentioned hardware failure precluded achieving this goal. This problem was unfortunate since only very limited hydrographic intercomparison is possible, but it very vividly illustrates the section of the shoreline which is logistically difficult to map using conventional techniques.

A gap in the AOL profile between the terrain and bathymetric record is apparent in each of the figures. The seaward end of the terrain profile stops abruptly at the location of the beach/water interface at the time of the airborne survey. This gap, which varies from >1 m to ~1.5 m (2-5 feet), indicates the section of the AOL hydrographic record in which the laser surface and bottom return signals were convolved to a point where our present techniques could not dependably provide separation. New analytical methods are currently being explored for resolving this problem.

Figure 6 is a comparison of the airborne laser profile data with two surveys furnished by COE from previous studies conducted in June 1980 and April 1981. (For the sake of comparison, the beach data were not filtered.) The temporal differences between these conventional surveys and the airborne survey is, of course, far too large to permit any quantitative comparison, especially in the submerged area adjacent to the beach. The positive portions of the profiles are only in fair agreement and the agreement between the conventional surveys is no better than each compared separately with the airborne profile. Figure 5, however, graphically demonstrates the rather large changes in the local morphology of the shoreline in a relatively short period of time and underlines the potential importance of an airborne lidar system in the capacity of providing shoreline profile reconnaissance for numerous applications.

Figure 7 is a comparison of the two AOL profiles made over flight line 5. The differences between these surveys are an indication of the spatial variations in the shoreline over relatively a small area. While the positioning and navigation during the mission flown at night is insufficient to quantify the horizontal separation of these lines in the plane parallel to the beach they are each estimated to be within  $\pm 30$  m of the intended common target which was a strobe light positioned on the beach. All of the profile passes had similar cross-track positioning uncertainties and care should be exercised in evaluating agreement with the surface truth data in a quantitative sense. Attention should be given to this aspect on future experiments. Under daylight conditions a combination of photography and inertial navigation system inputs will yield much improved horizontal control. As will be pointed out however, additional laser power will be required to yield a useful depth of penetration in water as turbid as that encountered at Wrightsville Beach.

As can be observed in Figure 1, most flightlines extended into the area behind Wrightsville Beach. This allowed for bathymetric measurements in the Banks Channel and Intercoastal Waterway areas. Figure 8 is an example of data extracted from the Banks Channel portion of pass 5/1. Figures 10 and 11 are 3-D images of elevation data from two scanning

passes. Flight line 10 was designed to collect a data set centered on the beach/water interface (refer to Figure 9). Line 10/1 was flown south-to-north. Line 10/2 was flown in the opposite direction and consequently the data displayed in Figure 11 have been geometrically reversed end-for-end for ease of comparison. The feature protruding into the water is Crystal Pier, near flight line 5. The condominium just north of Crystal Pier shows up quite well in both images.

One of the technological advances accomplished with this data set was the processing of the data to yield a combined above-and-below-water elevational surface. Briefly, the problem encompasses recognizing which individual samples are from land targets, and which were recovered from water targets, requiring further processing of the digitized time-waveform history to yield depth. To the best of our knowledge, this is the first time that a combined hydrographic/terrain three-dimensional digital data set has been produced with an airborne laser system.

Figures 12 and 13 are a 3-D and contoured projections respectively of the composite data from passes 10/1 and 10/2 for the section of beach around Crystal Pier. The contour intervals in Figure 13 are in meters, and are biased by 10 to eliminate negative contours (a temporary limitation in our software). Thus the contour line labeled "10" is the beach/water interface. Utilizing matrix processing software developed during the NASA/COE terrain mapping project both data sets were registered on a "real world" coordinate system and subsequently combined. The detail in the pier and the condominiums that was successfully carried through in the processing is a clear indication that reasonable horizontal control has been achieved. The combined composite from the two passes represents a considerable potential improvement over the individual scanning passes themselves in that (1) an increased data density is available, (2) any horizontal control problem becomes obvious, and (3) small airplane attitude problems reflected in the data that were not entirely removed during the processing are dampened. The increased data density is especially important for resolving bathymetry where a higher percentage of pulses are rejected during waveform processing.

#### CONCLUSIONS

The use of an airborne lidar system to perform shoreline mapping presents a number of system requirements somewhat different than previously encountered in experiments in either hydrography or terrain mapping applications. Increased turbulence along shorelines creates added turbidity and foam. Further, the amplitude of ocean swells and waves increases significantly as the shoreline is approached posing additional difficulties in establishing the bathymetric surface. Truthing the lidar results is likewise a problem. Shoreline features are so ephemeral that surface truthing must be performed within days, or even perhaps within hours, of the airborne survey.

The preliminary results presented in this document provide sufficient evidence of the potential of an airborne system for providing shoreline mapping surveys. The AOL profile records indicate good internal consistency and reasonable agreement with the available surface truth. These records also demonstrate that newly developed techniques from the AOL terrain mapping program can be utilized for the removal of short-term aircraft vertical motion (Krabill et al, 1980). This capability allows a total range vector between the aircraft and the ocean floor to be utilized to remove the effects of waves in the bathymetric record.



The scanning passes flown over the land/water interface allowed refinement of algorithms for recognition of pulses striking land and water targets (Swift, 1980). Further, these data sets serve to indicate the degree of horizontal control that has been developed for processing scanning data and represent the first combined three-dimensional hydrographic/terrain lidar data set.

The resolution of bottom returns from depths shoaler than 1 m continues to be a problem hampering lidar application to shoreline mapping. The deconvolution of overlapping surface and bottom return laser signals cannot be accomplished with present techniques. Although the area between 0 and -1 m is generally relatively small, it is an important section in beach processes. Other techniques employing pulse width and bottom return amplitude are currently under investigation and will be reported later during the presentation of the final results.

The hydrographic data acquired with the AOL at Wrightsville Beach indicates that standard profiles along coastlines can be taken with an airborne lidar system. The major obstacle to utilizing the AOL for this application is the power limitation of the currently available AOL laser. In order to partially offset this handicap, the AOL was flown at night under low background light conditions. This permitted the receiver FOV to be increased and allowed the removal of the narrowband interference filter, thus reducing the signal to noise ratio (SNR). A higher power laser would have provided similar SNR and results under daylight conditions. The 2 kw neon laser used during this experiment is well below eye safety considerations. Recent improvements in laser technology have provided relatively high speed, high power blue-green lasers. Frequency doubled Nd:YAG lasers are already being utilized in airborne systems in Canada (O'Neill, 1980) and Australia (Penny, 1980). In the near future shorter pulse width lasers that will be able to operate at increased peak power but still within eye safety limitations, will be available (White, 1981). These laser developments promise both improved accuracy and depth of penetration.

#### ACKNOWLEDGMENTS

The authors wish to express their thanks to the numerous individuals from the COE, NASA, and EG&G without whose support this experiment could not have been accomplished. In particular, we wish to acknowledge the individual effort made on the part of Glenn Boone of the COE Wilmington District for his operational support and preparation of the ground truth data.

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# WRIGHTSVILLE BEACH PROFILING FLIGHTLINES

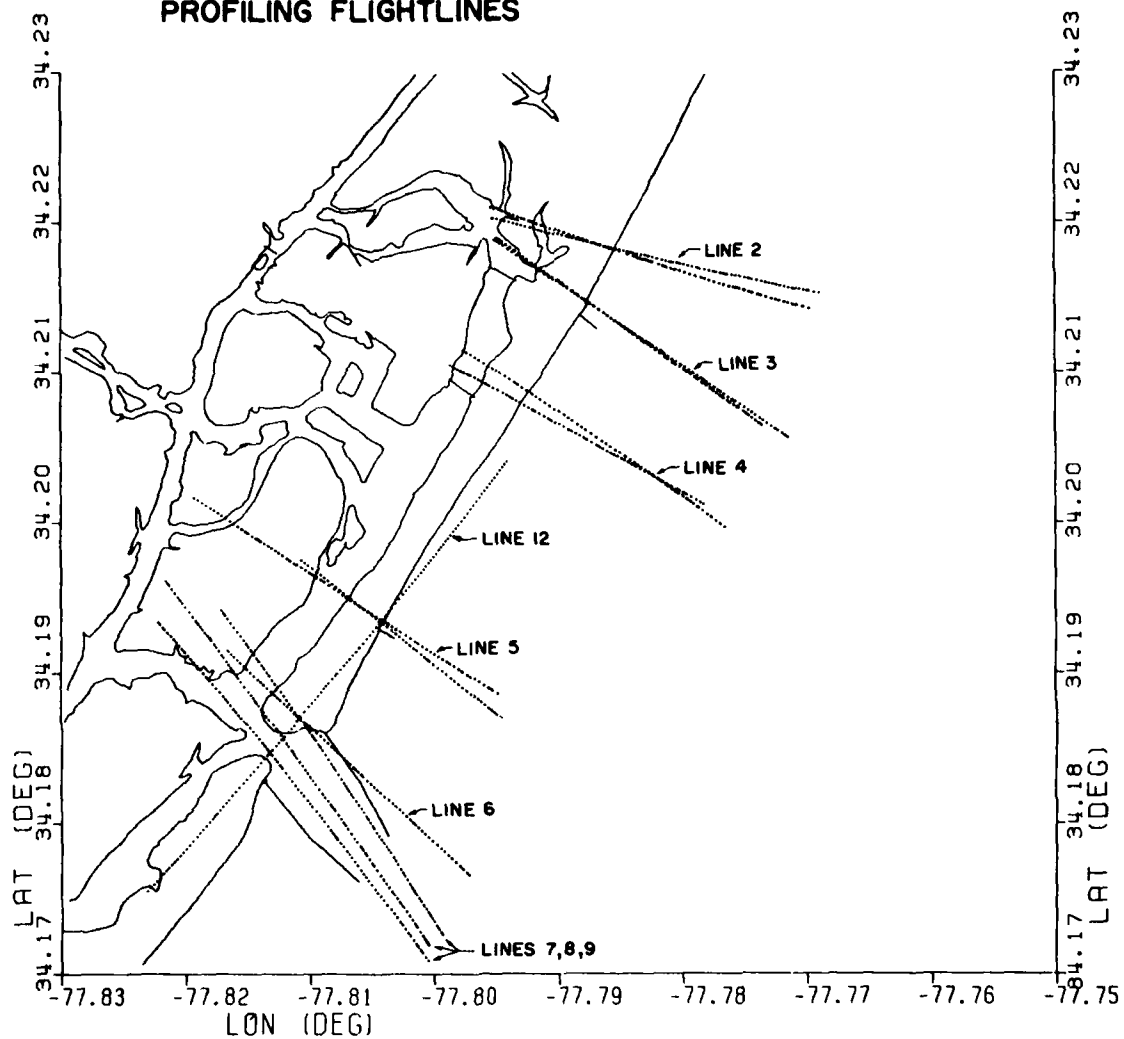


Figure 1. Map of Wrightsville Beach, NC, Area Showing Location of Profile Lines.

BA P-3 M-5 FL-4-1

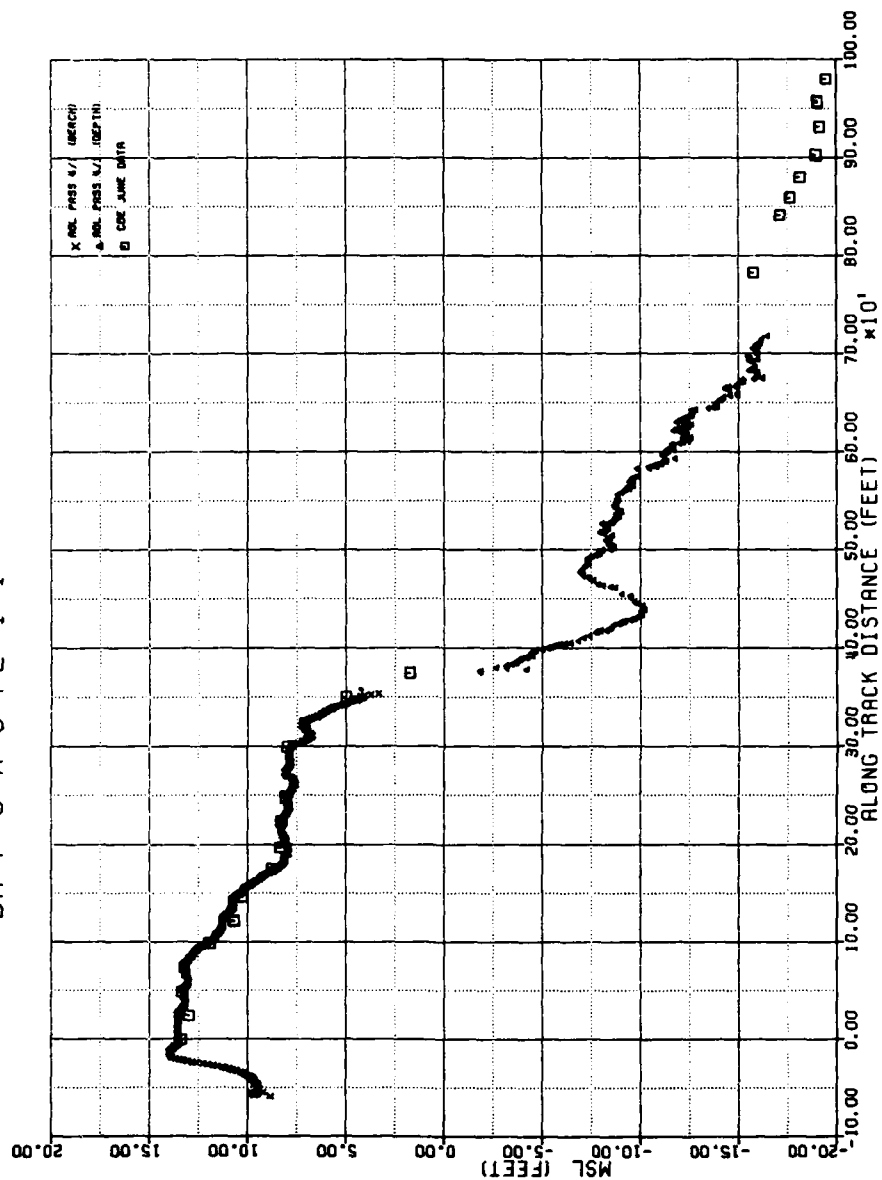


Figure 2. Surface/Subsurface Profile Data - Pass 4/1.

# BA P-3 M-5 FL-4

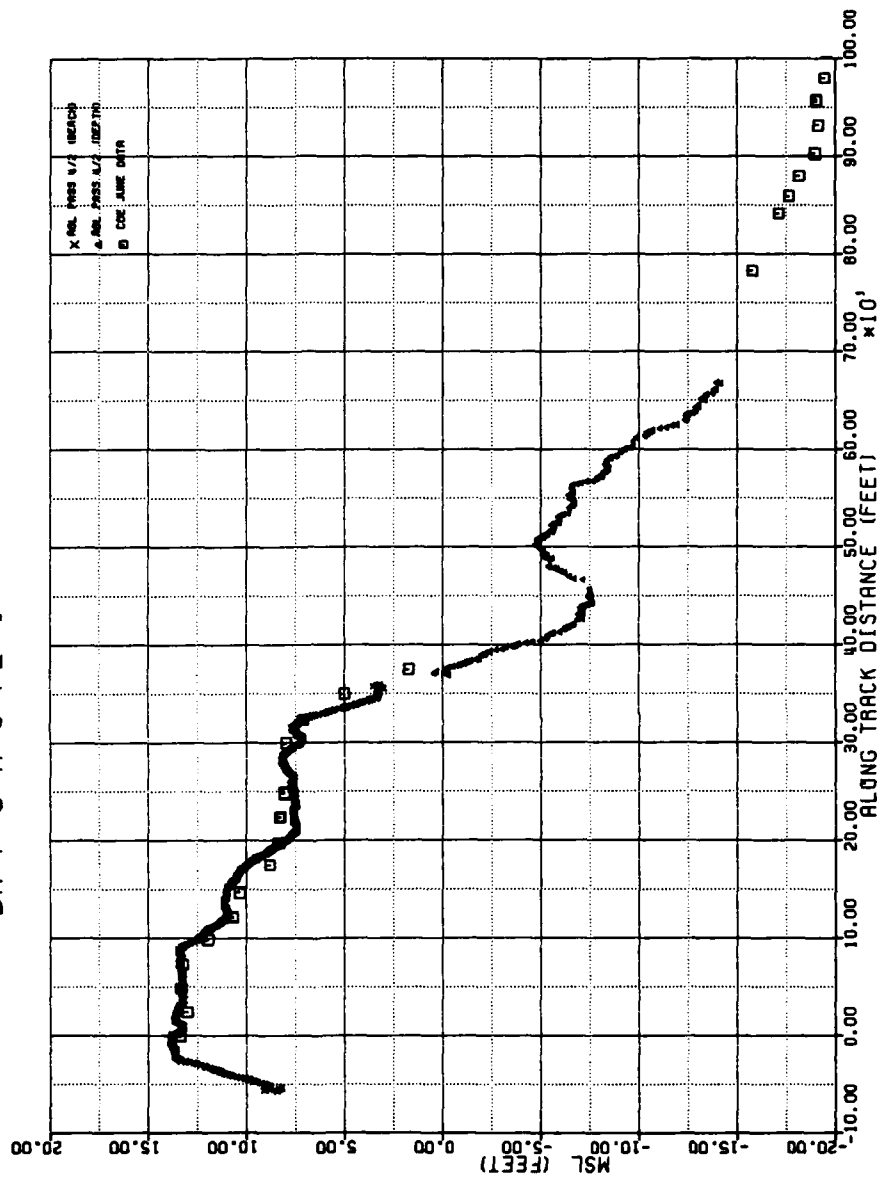


Figure 3. Surface/Subsurface Profile Data - Pass 4/2.

# BA P-3 M-5 FL-5 (CRYSTAL PIER)

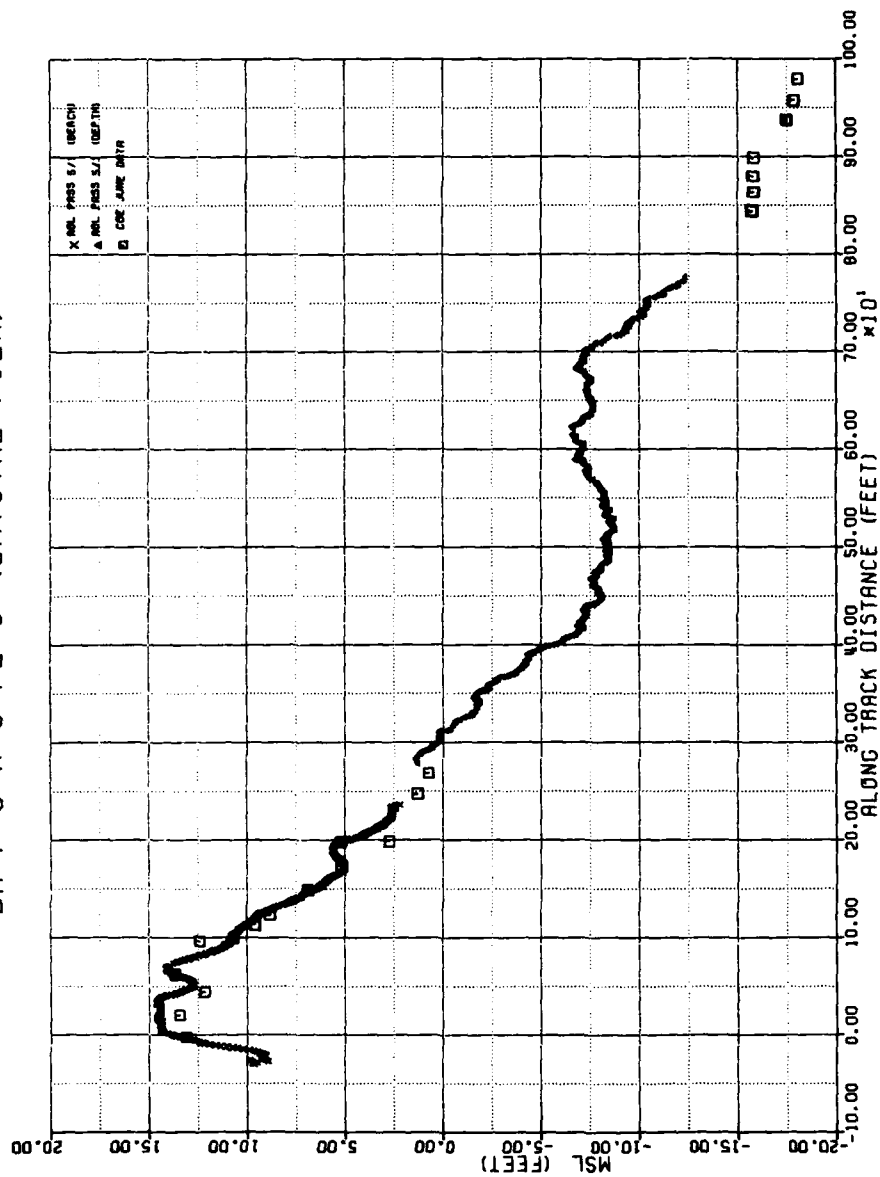


Figure 4. Surface/Subsurface Profile Data - Pass 5/1.

# BA P-3 M-5 FL-5 (CRYSTAL PIER)

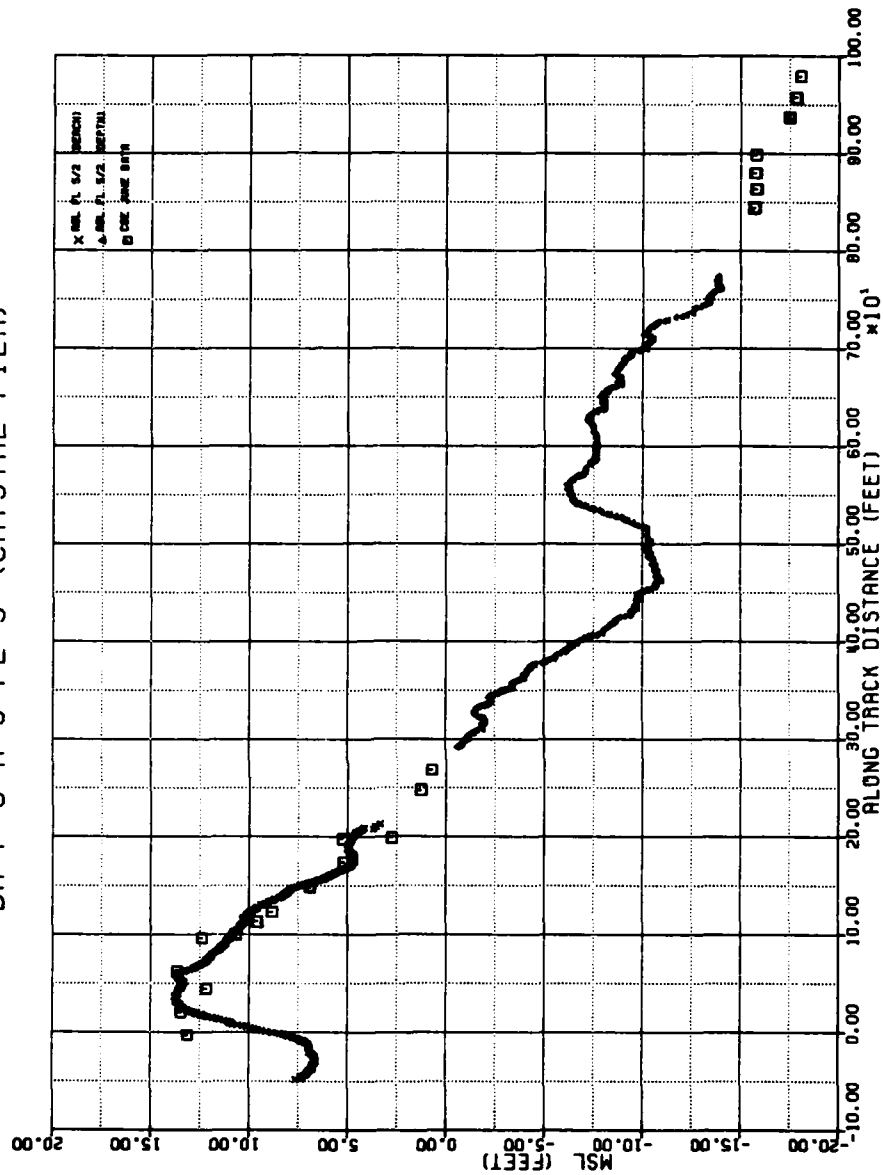


Figure 5. Surface/Subsurface Profile Data - Pass 5/2.

# BA P-3 M-5 FL-5 (CRYSTAL PIER)

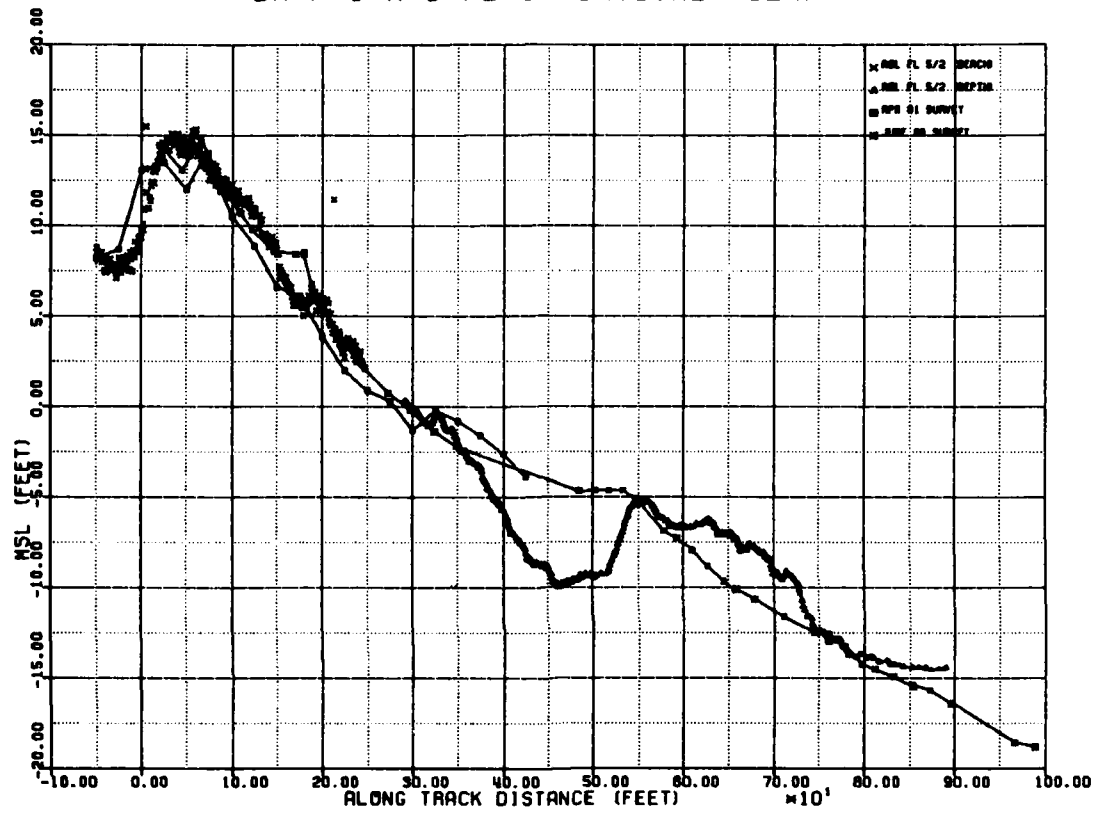


Figure 6. Comparison of June 1981 Airborne Laser Data with Surveys Made by the COE in April 1981 and June 1980.



# BA P-3 M-5 FL-5 (CRYSTAL PIER)

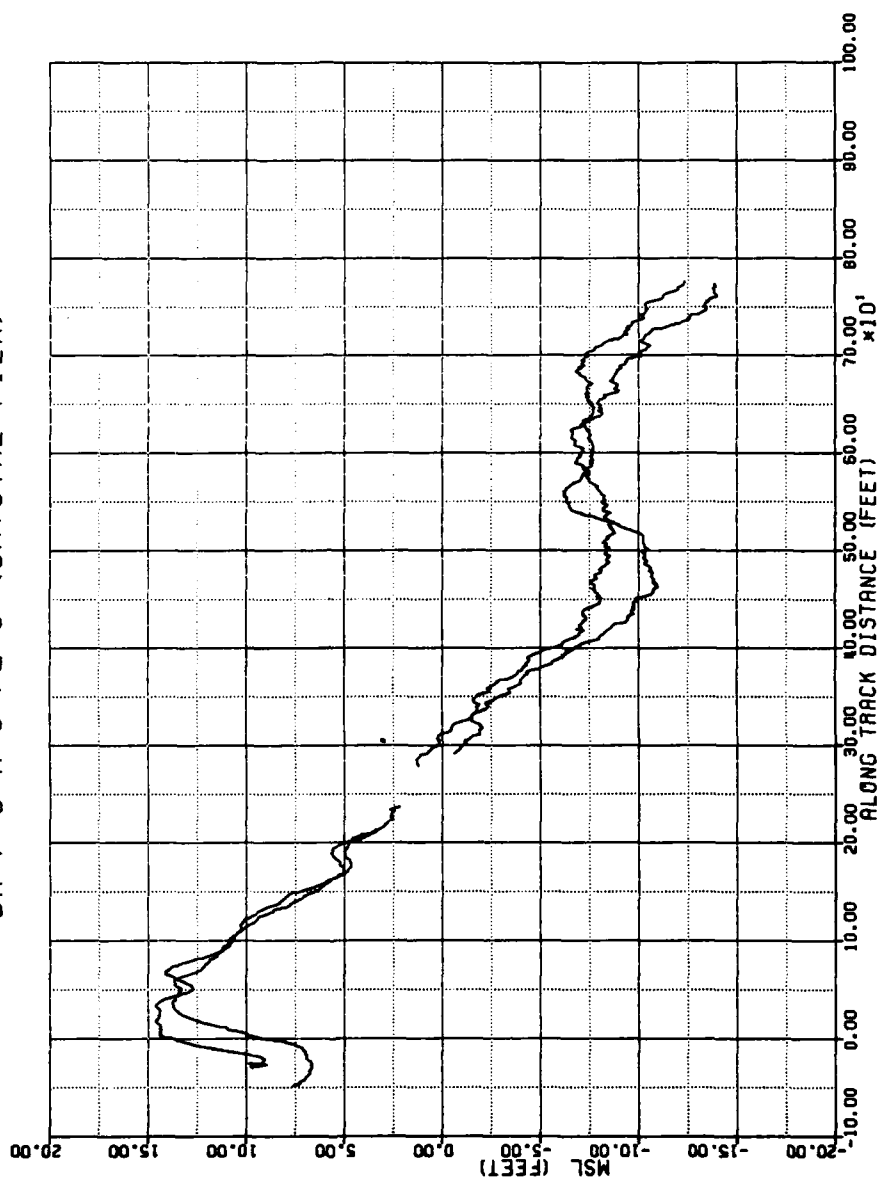


Figure 7. Comparison of Both AOL Data Sets on Flightline 5.

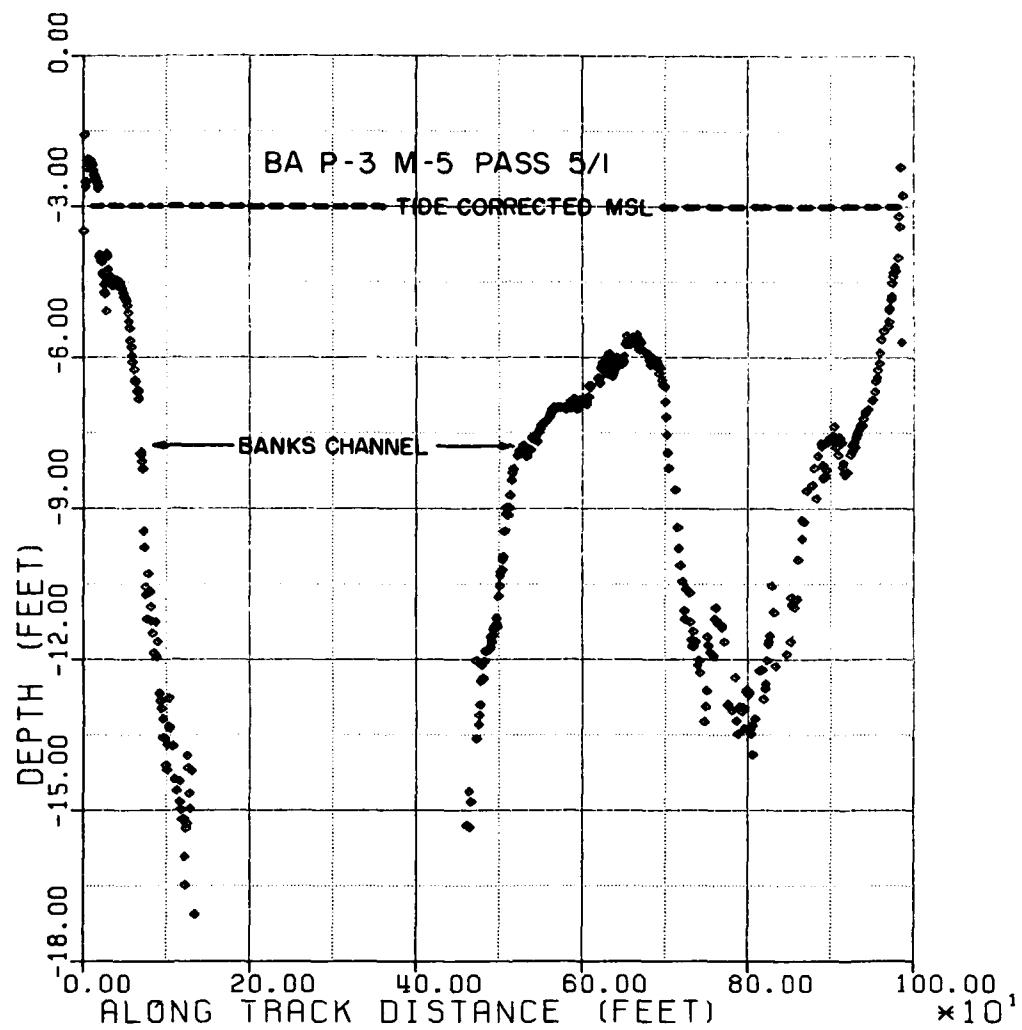


Figure 8. Bathymetric Profile Across Banks Channel Behind Wrightsville Beach.

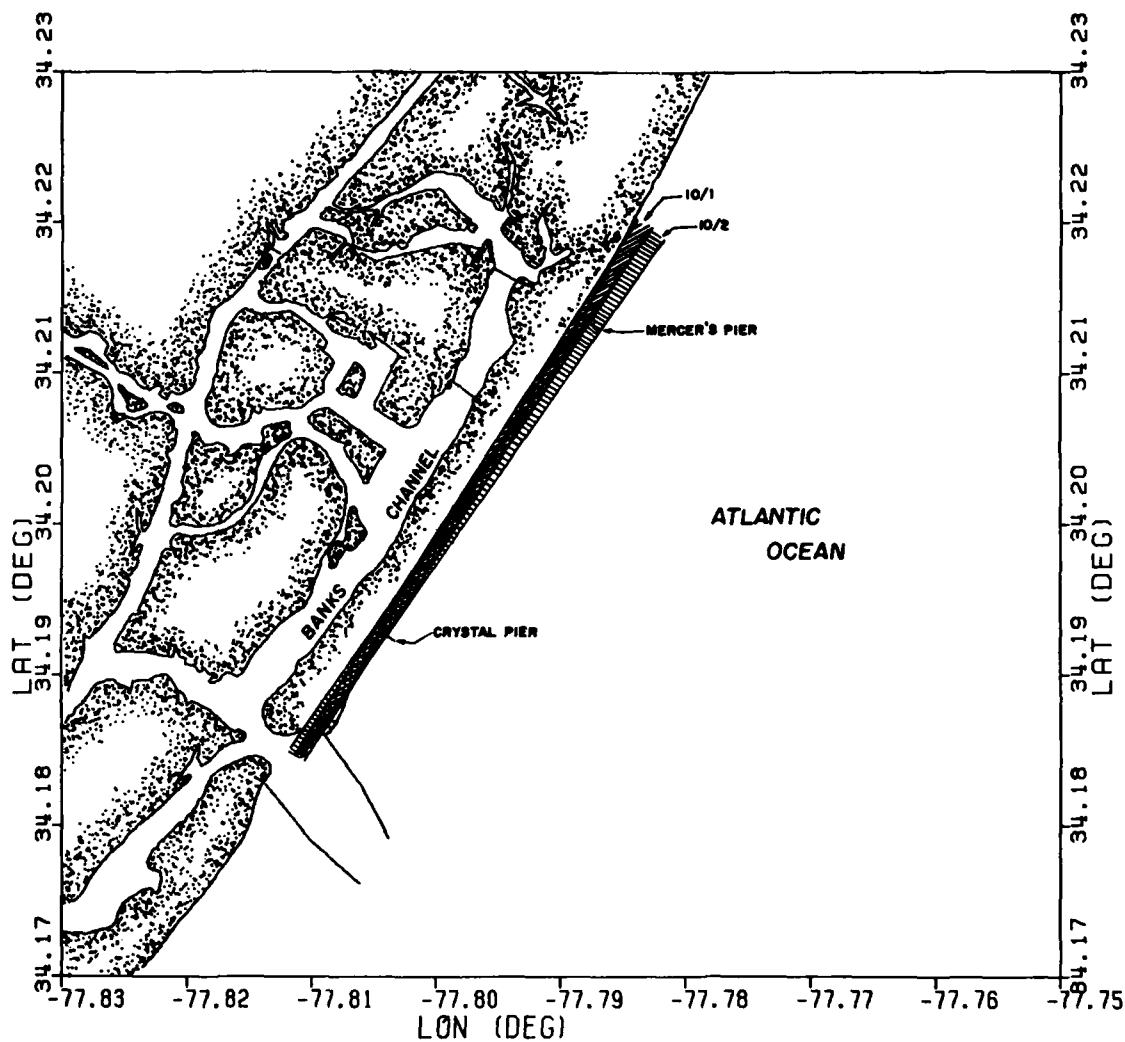


Figure 9. Map of Wrightsville Beach, NC, Area Showing Coverage of Scan Data.

CRYSTAL PIER AREA OF FLIGHTLINE 10/1

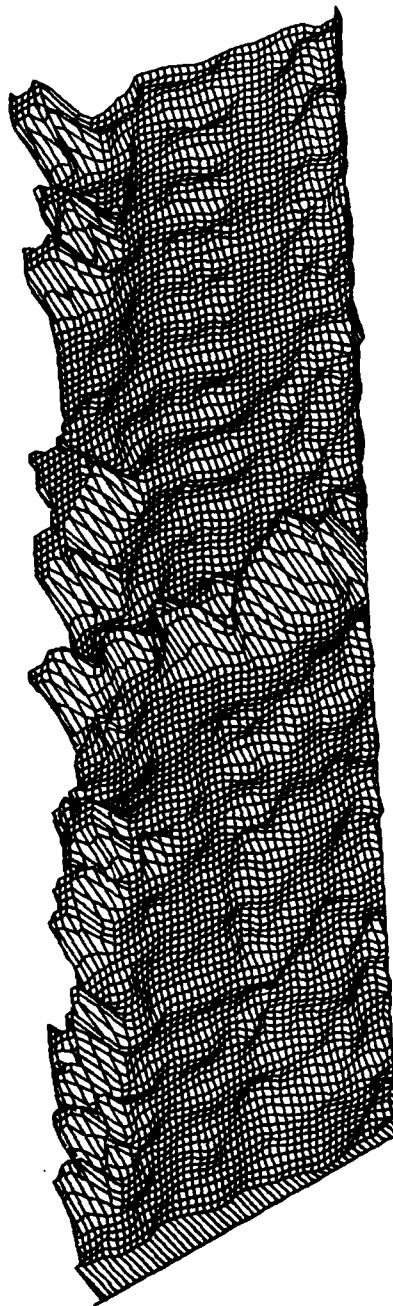


Figure 10. Perspective 3-D Image of a Portion of Processed Scan Data from Flightline 10/1.

CRYSTAL PIER AREA OF FLIGHTLINE 10/2

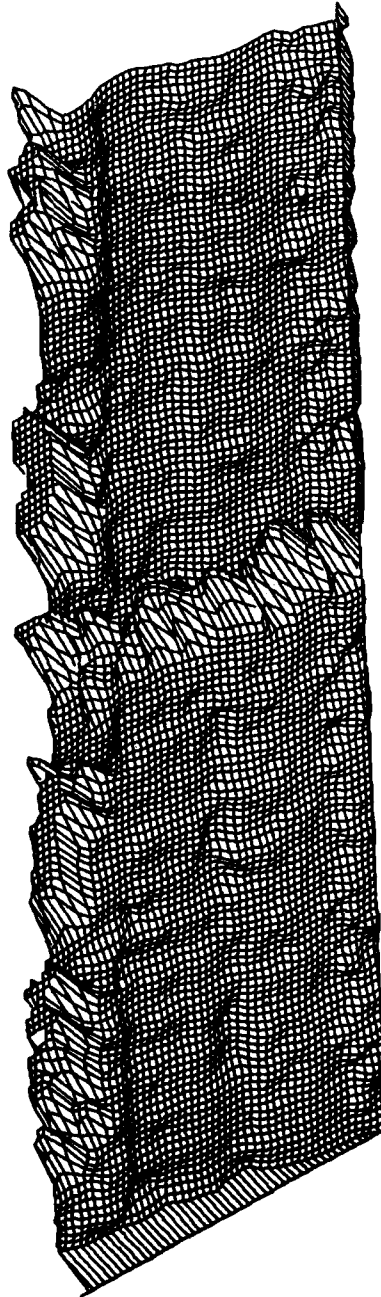


Figure 11. Perspective 3-D Image of a Portion of Processed Scan Data from Flightline 10/2.

COMPOSITE (LINES 10/1 & 10/2) OF CRYSTAL PIER AREA

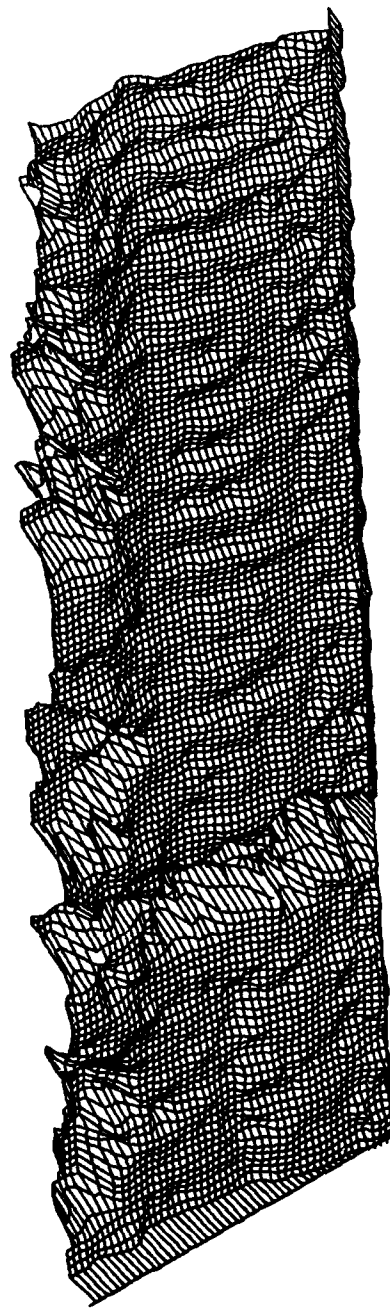


Figure 12. Composite of the Data from Flightlines 10/1 and 10/2.

# COMPOSITE (LINES 10/18 & 10/2) OF CRYSTAL PIER AREA

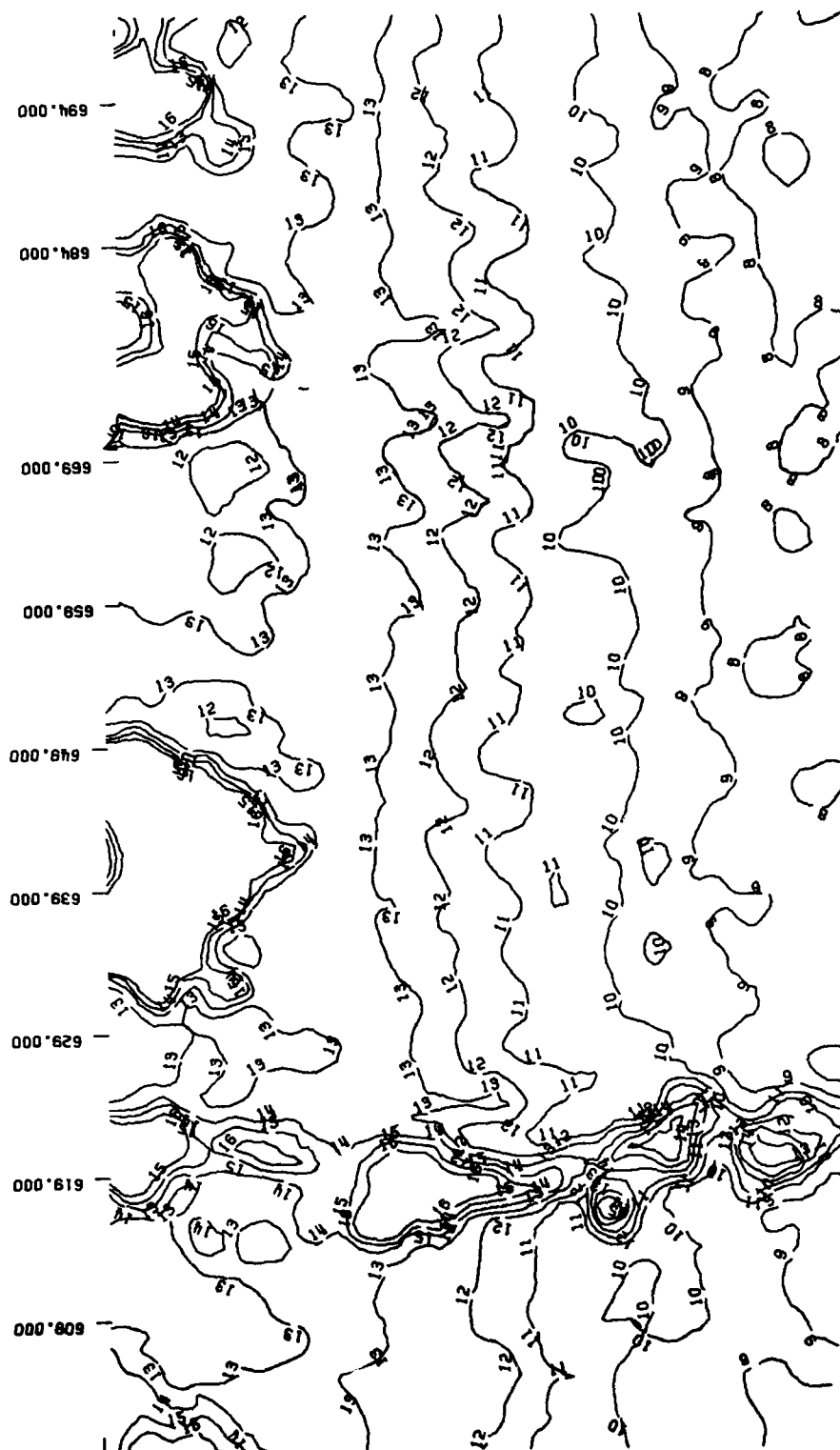


Figure 13. Contour Plot of Composite Data (Elevated by 10 meters.)

AD-A117 036

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U.S. ARMY CORPS OF ENGINEERS SURVEYING REQUIREMENTS MEETING, 2---ETC(U)  
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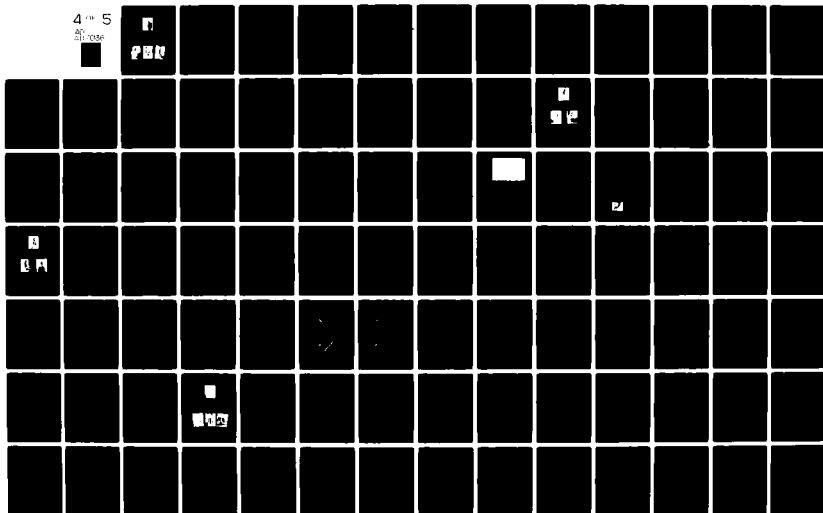
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SESSION IX: CONTROL

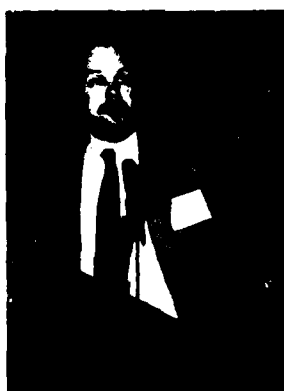


M. K. Miles  
OCE  
Chairman

*Speakers*



Trevor Parish  
Murphy Parish Kilgore, Inc.



Jim Stem  
National Geodetic Survey



T. F. Conlon, Jr.  
Span International, Inc.

## SESSION IX

### CONTROL

#### Summary

Control surveying and national datums were discussed. The importance of true positioning for survey data was discussed by Mr. Trevor Parish of Murphy/Parish/Kilgore. The North American Datum (NAD) of 1983 and the National Geodetic Vertical Datum (NGVD) of 1987 were outlined by Mr. Jim Stem of the National Geodetic Survey. Highlights included the projected differences in latitudes, longitudes, and heights throughout the nation. It was noted that these upcoming changes would have a direct impact on Corps surveying and mapping activities. Mr. M. K. Miles of the Office, Chief of Engineers, suggested that newly formed technical working groups should begin to discuss these changes and how they will affect the Corps mission. Geodetic control surveying using inertial technology was discussed by Mr. Tom Conlon of Span International, Inc.

## THE IMPORTANCE OF CONTROL VERIFICATION IN OBTAINING "TRUE POSITION"

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Birmingham, Michigan 48011

### BIOGRAPHICAL SKETCH

Trevor N. Parish is vice-president of Murphy Parish Kilgore Inc., Consulting Engineers, Surveyors and Architects of Birmingham, Michigan. Born and educated in the United Kingdom, he spent several years carrying out land and hydrographic surveys throughout the British Isles, before emigrating to the U.S.A. in 1976. Mr. Parish is a licensed land surveyor in Michigan and a member of the Hydrographic Society, The Guild of Surveyors, ACSM and the MSRLS.

### ABSTRACT

The paper relates the author's experience of the very real problems facing surveyors as to the accuracy and validity of the fundamental control upon which their work is based and its effect upon the determination of true position for any acquired data.

The subject should be of concern to all surveyors, but especially to those actively engaged in the establishment of control systems to support hydrographic and topographic surveys, together with work in the field of cadastral (boundary) surveying.

It should be noted that the term "true position" for this discussion is the true location of any acquired survey data and the proper connection of this into any particular map projection in order to yield its correct relationship with other acquired information.

In short, the whole idea of what a map sets out to do.

The paper attempts to identify some of the potential problems that arise, and make suggestions as to corrective steps that might be taken.

### INTRODUCTION

It is certainly no news to the practicing surveyor that in the last 15-20 years (at least), the survey industry has been experiencing tremendous advances in the state of the art of instrumentation available in data acquisition systems.

Onshore these advancements have included: the development of the electronic distance measuring instrument; the refinement and enhanced competitive market of the theodolite; introduction of total station systems with data recording and computer interface plot capabilities; and of course the great advances in the fields of inertial and satellite positioning.

Offshore: the development and refinement of the variety of radio and acoustic positioning systems available for location in coastal regions, as well as oceanic applications; refinement and digitization of depth sounders; introduction and rapid advancement of hardware and software to complete the totally automated hydrographic system; offshore applications of satellite systems also.

This equipment (with care) has yielded the possibility of much increased precision and potential accuracy coupled with more rapid data acquisition, but with (in general) reduced user effort.

However, this improvement in the method of acquisition and standard of data has led to a magnification of a timeless problem that will never be totally rectified by the development of instrumentation, a subject that is at the very basis of our profession.

Through better and easier position determination it has allowed us to check and identify more readily the validity of existing control upon which our work is to be related.

The confirmation of the "credentials" of any control point is of utmost importance prior to use if we are to minimize the wastage of time and money in any operation.

It is yet even more critical today. The automated systems currently in use with their potential for acquiring tremendous amounts of data over much larger area, can turn a smoulder into an explosion.

#### CONTROL PROBLEMS

Problems with control may arise for any number of reasons but might include:

(1) Inaccurate surveys. These are not necessarily intentional, but could be the result of poor equipment, poor terrain, poor mathematical considerations, etc. - it just wasn't that angle or that distance. REMEMBER - You've probably got a 1" or 10" Theodolite, and an EDM to measure a mile at a shot. Don't underestimate what some other poor surveyor may have gone through to achieve his results.

Problems can arise when this work is used as the basis for an extension of the control network, which obviously promulgates further inaccuracies.

(2) Piecemeal Surveys. Local (or site) control systems established to meet the needs of a specific job - and that alone. Normally caused due to the "I need it, I need it!" syndrome. Symptoms being when your instructions may include the following:

- (a) Last Tuesday's date is listed under "completion deadline".
- (b) You are advised to watch out for 24 impatient-looking dredging men who will be watching your every move.

(c) We know what money and budget is, but please don't use it on this job.

(d) Note Re: Personnel - Due to 10 of our staff attending an "educational" conference in Hawaii, please hire and train your crew locally.\*

\*

(This is also in conformance with the Legislative directive to utilize local community resources.)

Seriously, these surveys are established to meet the job in hand without concern for future use.

(3) Poor notes and records. Data acquired over some time (it doesn't have to be long) can be lost, misidentified and just plain overlooked. Also, it is no minor point that coordinate values, elevations, station descriptions, etc. may have been updated by another agency without your knowledge and have established a revised set of values for the point or points in question.

(4) Confusing field recovery. The exasperating extension of Item (2) and (3) is the field recovery of the physical monumentation. Often several surveys have been carried out in the same site area only to leave a variety of monumentation within a few feet of one another.

This can obviously lead to misidentification, and the subsequent invalidation of any amount of survey data that has been based upon the particular point.

(5) Poor field and office investigation. The main excuse offered in defense of this is the usual "time and money" argument.

Incomplete data may be obtained and field investigation is kept to a minimum. Let's get on with the survey and worry about that later - perhaps it will resolve itself or go away.

#### Examples

(1) As part of our company's investigation of U. S. Public Land Survey section corners within a particular township we obtained recent (within 5 years) witnesses for one corner recorded by a surveyor with the county register of deeds in conformance with State Law.

We located this point from these witnesses and found a 1" iron pipe located near the surface of an aggregate roadway, which had been raised above the poorly drained area existent in its vicinity.

However, our further search of the general location revealed a cedar stake located some 20 feet away and 5-6 feet deep below the surface of the roadway. After further analysis and reference to the original G.L.O. notes, we believe the stake to be at the true position.

Unfortunately, several surveys had been carried out in the general area based upon the 1" iron pipe, which proliferated the problem - not an uncommon situation.

(2) On another project our work on property adjoining the Detroit River involved the establishment of the harborline & streetlines.

We acquired data from various agencies in order to run our control work.

Some of control/boundary points were noted to be possibly destroyed.

Our field research uncovered with some effort the "destroyed" points, and via the State Plane Coordinate System that we had tied into, we were able to recover a monument we had been unable to locate to date.

The point was found within 0.10 feet from where we had computed its position based on our control work.

(3) Our firm was called in to assist another survey company on control work. The company had been awarded a contract to carry out hydrographic survey work over many miles of a major river and its tributaries.

The project consisted of carrying out surveys along specific range/section lines established to make section comparisons of the conditions of the revetments on the levees adjoining the rivers.

Until recently the surveys had been carried out using manual methods of positioning based upon the physical location of base lines and their points of intersection, (P.I.), together with physical points established to mark the visible part of the range lines. (I believe wire wheels had been used.)

The survey contractor's method of operation utilized range-range transponders, digitized sounder coupled into a fully automated on-board data system. Underway, each of their survey vessels was capable of completing (conservatively) 100 of the range lines per day.

What follows is frightening, and as of this writing I'm not sure the story is over yet.

Available Horizontal control information in the form of various schedules was furnished to them by the client. This generally consisted of a listing of the baselines P.I.s and the related range lines together with stationing and coordinate values, however, exclusive of witnesses.

To enable sound geometrical figures for the location of transponders, further control work was carried out to supplement the furnished data. Per contract requirements all work had to be related to the existing baselines and that alone. Connection to an established grid system e.g. State Plane, was not required.

It was at this point that the plan changed. Utilizing Theodolite and EDM procedures, additional traverses connecting recovered P.I.s at the beginning and end of many revetments (generally 2-3 miles long) were misclosing by 5, 10, 50 or in some cases hundreds of feet.

After much consternation and frustration it was discovered that there were often 2 or 3 monuments located within 10 feet of one another at the P.I. locations.

The problem of resolving which was the correct monument and how it related to the range lines was further complicated by coordinate values based on local coordinate systems without a common base to assess their relationship.

After some time the client at least acknowledged the problem, but relief was still far from just around the corner.

In the meantime, the survey contractor suffered severe loss in work production, having initially hoped the problem was localized. However, this was not the case. Having two fully equipped survey vessels and crews on site, with little productive work to accomplish whilst this was going on, coupled with not being paid because production was down, was extremely frustrating to say the very least.

Obviously, he also had to pay out for our fees in order to try and assist in getting things resolved.

#### PLAN OF ATTACK

Having identified these various areas of concern, what can be done to change this for the better? Though the existing may be history and cannot be changed, there are certain procedures that may at least help to minimize the kinds of problems we have discussed here; and we, if we are to be professionals, must be prepared both technically and morally to do it.

(1) Reference datums. Wherever possible control should be tied into a referenced datum. The State Plane Coordinate Systems offer an excellent basis for horizontal control work. The specific Vertical control datum to be used would probably be more dependent on the particular project area. However, most datums of merit have been related to National Geodetic Vertical Datum of 1929, so this can be used and the appropriate conversions made.

This may seem like an obvious statement. However, from a practical standpoint, it is often overlooked, normally for the "time and budget" reason, which history has repeatedly proven to us is a poor investment.

One of the major benefits of any reference datum is recoverability and retracement.

For instance, with your original points being tied into State Plane Coordinates their location can be restored even if they are all destroyed. And obviously if you can restore the control, you can restore the location of all the other work that was carried out relative to them.

I cannot over-emphasize this point.

(2) Other options. Looking at reality we know that this is not, and will not be, happening in a lot of cases, so we have to be sensible and acknowledge this fact and decide on what else we can do.

One suggestion would be that if you are working on just a local system, with the equipment we have available today it takes very little extra time and effort to carry out observations to a standard acceptable for connection to future datum control. In this fashion at least you're offering some input for the future and perhaps the work won't be totally disregarded at that time.

In short, act like it will be part of a referenced datum, and utilize as many of the rest of the guidelines as possible, suggested herein.

(3) Site selection. When establishing control be careful to consider the work area and on-site conditions.

Take time to review the potential of each monument being obliterated or destroyed. You owe this to the next poor guy who has to find this point - it may even be you.

If erosion, construction or travel, etc. seems likely, assess the possibilities in locating your control in the vicinity of existing physical structures, e.g. lights, day-boards, docks, etc. to better assure longevity. If this is not possible due to other more important considerations for this survey, when running horizontal control attempt to obtain reference side shots (angle and distance) to whatever points may be available. They could be the difference between "here we are" and "here we aren't".

(4) Documentation. Whatever work is carried out should be documented to the best of your ability. This doesn't necessarily mean camera ready for publication, or in gothic print, but just do your best to relate what was going on at the time of survey. Sketches, short notes and obviously of great importance - WITNESSES wherever, whenever and whoever possible.

REMEMBER - We are supposed to be discussing the verification of control. That in part means identification and recoverability, as opposed to misidentifying a point you can't find.



(5) Monumentation. The physical monument itself obviously plays an important role in longevity. The initial cost may be more - materials and labor, but you only get what you pay for.

NOTE: (a) No 18" re-bars in 5 foot deep swamps please.

(b) Also use something with magnetic capabilities. It is so much more efficient to use a magnetic locator e.g. Schoenstedt - perhaps I'm lazy, but I hate digging holes when it's not necessary, and I know that's the way property owners feel when you are searching in their prize flower garden.

(6) Furnished data. Another major part of control confirmation is the verification of the furnished data in itself.

One could argue that it is not the surveyor's responsibility if documents are to be furnished as part of the contract. However, would you drive a car without checking out at least that it had wheels or the brakes worked, just because it was given to you?

It is the surveyor's own insurance against potential professional liability and other work procedure problems to make his own check of the data. Initially, this can include checking with all agencies that may have information for the project area. As I mentioned earlier, it is not uncommon for another agency such as National Geodetic Survey to have updated information regarding the control you will be using. Better to find out before you start.

Also, take a few minutes to discuss with the client his or their knowledge of how, when and why the control was established. It may give you an indication of your future.

If possible, make a computational and work plot analysis of the data. With available mapping, does it at least plot in the right vicinity?

(7) Problem identification and correction. The final point here surrounds the responsibilities of both parties (client and surveyor) involved with the project. What happens when the surveyor identifies a problem with the record data or with physical problems in the field?

This could be any of the problems we covered (or didn't) in the earlier section. Suddenly, we have a nasty, often embarrassing situation which must be addressed and resolved. Unfortunately too often the surveyor who raises the question is labelled the BAD GUY.

We haven't had problems with it before, so how come you are?

The client MUST acknowledge his responsibility to the problem rather than allowing the surveyor to become the "stuckee" and endure the total burden of this unforeseen circumstance.

The surveyor should obviously document and advise his client of differences/inaccuracies as soon as reasonably possible. The knowledgeable client should be prepared to deal with a potential situation.

One suggestion might be to include a statement in contract documents to the effect "should any existing control data be determined to be in error, prompt notice should be given to this agency in writing, to include documentation of inaccuracies found".

Perhaps this would at least start corrective wheels in motion, and take some of the financial burden off the surveyors back.

#### CONCLUSION

In closing, I hope at a minimum this epistle has identified a potential problem.

Its intent was to instigate further discussion of a subject which we may easily kid ourselves will go away with all the new high powered toys we have to play with.

If someone can convince me that we can accurately record and monitor the existing conditions both on and off shore, and make true comparisons of that data without the confirmation and verification of control, I'll welcomly buy them a beer. You can't imagine the sleepness nights they will have saved me!

#### ACKNOWLEDGEMENTS

The author wishes to express his thanks to Messrs. James M. Murphy, Anthony G. Stephenson and Colin G. Weeks for sharing their thoughts on certain portions of this paper.

NORTH AMERICAN DATUM (NAD) OF 1983  
AND  
NATIONAL GEODETIC VERTICAL DATUM (NGVD) OF 1987

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BIOGRAPHICAL SKETCH

James E. Stem is a Geodesist in the Office of the Director of the National Geodetic Survey, NOS, NOAA. Prior to this assignment he was a Supervisory Geodesist in NGS's Control Networks Division where he analyzed projects for the 1983 NAD. Mr. Stem received a B.S. degree in Mathematics in 1966 and a M.S. degree with a Major in Geodesy in 1971 from Purdue University. Professional affiliations are the American Congress on Surveying and Mapping (ACSM) and the American Society of Civil Engineers (ASCE).

ABSTRACT

The National Geodetic Survey (NGS)/National Ocean Survey (NOS) is responsible for the determination of the National Geodetic Reference System (NGRS) for the United States. The NGRS consists of several reference systems and Datums. Determination requires definition, field surveying, and computing.

The present reference system for horizontal surveys is defined by the North American Datum (NAD) of 1927 and the present reference system for vertical surveys is defined by the National Geodetic Vertical Datum (NGVD) of 1929. New technology and 50 years of additional surveying have antiquated these Datums. The NGS is currently engaged in two programs to update the NGRS, creating the NAD of 1983 and NGVD of 1987.

Mr. Stem will review the problems with the current Datums, review the activities and status of the two new Datum projects, and discuss the effect of these projects on the surveying community.

GEODETIC CONTROL SURVEYS  
STATE OF MICHIGAN - 1981

Thomas F. Conlon, Jr. L.S.  
Span International Inc.  
Reston, Virginia 22091

BIOGRAPHICAL SKETCH

Tom Conlon is a sales executive with Span International, Inc. and a Registered Land Surveyor. In his 20 years in the surveying field he has covered a wide range of projects, from individual lot surveys to major multi-state transportation projects. Prior to his employment at Span International, Mr. Conlon worked for Maddox and Associates, Inc. and worked extensively on the 'Mobil Automated Roadway Survey' project for the State of Michigan which ultimately led to the geodetic control survey reported herein. Mr. Conlon is a Registered Land Surveyor in Connecticut since 1972 and an active member of A.C.S.M.

INTRODUCTION

In the fall of 1981 the Department of Transportation, State of Michigan selected Maddox and Associates, Inc. Bethesda, Maryland, and Span International, Inc., Scottsdale, Arizona to complete an "Inertial Survey" of 300 new 2nd Order, Class II' geodetic control monuments. This project, done in close cooperation with National Geodetic Survey (N.G.S.) was the first time that a state agency elected to utilize "Inertial Surveys" as a means of establishing geodetic control. The inertial survey is the first part of a two step program which will eventually lead to having the road geometry for 40,000 miles of primary roads in a digital data base, for use in accident prediction and analysis. In performing the Inertial Survey, Span International debuted 'GEOCERTIN', a new concept in planning, executing and adjusting inertial survey observations. The inertial survey took a total of 11 months to complete from the time of announcement of award to the completion of initial adjustment of all 300 stations. Major steps in the overall program included recovery and reconnaissance of existing control, construction of 300 new monuments, SPANMARK<sup>TM</sup> Inertial Survey observations and final adjustment by GEOCERTIN<sup>TM</sup>.

RECOVERY AND RECONNAISSANCE

M.D.O.T. assigned one survey crew from each of its maintenance districts, within the project area, the responsibility of recovering as many geodetic control monuments within their respective districts. In addition to the normal recovery instructions, specific instructions such as whether or not a four wheel drive vehicle or helicopter could directly occupy the stations and the best route to get to the station from a major paved road, were required.

As expected, the recovery operations found a small percentage of monuments lost or destroyed, however in areas along the coast line of Lake Michigan, erosion had destroyed a significant number of positions. Several traverse runs, not in the originally planned or monumented scheme of operations were subsequently planned, monumented and surveyed to provide a replacement network of stations in the area.

In working with N.G.S. it was pointed out to M.D.O.T. that there were operations currently underway in portions of Michigan to provide additional ties to existing arc's of triangulation. This work would have significant impact should any of the control values, subject to re-adjustment, be utilized.

The recovery and reconnaissance operations continued throughout the major portion of the project, primarily to insure that no changes in information, such as road construction, etc. would cause delays.

#### MARKSETTING

The standard NOAA/NGS prescribed monuments were set throughout the project area. These marks consisted of an underground mark; of an irregular concrete mass with a standard brown dish, topped with a poured in place concrete marker with standard brown dish, set 15 cm below the surface of the ground. Additionally each mark had an accompanying pair of reference markers also being poured in place concrete with standard "reference marker" discs. The task of setting the monuments was undertaken initially by crews of the Department of Transportation and were accompanied utilizing as much mechanization as was available (tractor mounted power auger and power mixer). By the early summer of 1981, some 260 monument positions had been established. Some markers were set in close proximity to existing control stations while others were set in remote locations where there was no access to existing control stations. In order to make a more homogenous network of stations, additional monuments were set at intersection points of North/South - East/West traverse runs, as well as at closer spacing between monuments all to provide a more user oriented network of monuments. Prior to the commencement of the Inertial Survey and during portions of its operation an additional crew from Maddox and Associates, Inc., Bethesda, Maryland, completed the task of monumenting a sufficient number of points to bring the final total of points to 302.

#### SPANMARK<sup>TM</sup> OBSERVATIONS

Prior to the commencement of field observations, SPAN International, Inc. had to demonstrate to M.D.O.T., via a field test, the accuracy of the SPANMARK<sup>TM</sup> system and its compliance with the contract specifications. Contract specifications for the inertial survey required that all traverses have a minimum length relative accuracy of 1:30,000  $\pm$  0.1m closure. This error ratio was in excess of the specification for "2nd Order Class II" accuracies, and it was felt that if the inertial survey system maintained the 1:30,000 accuracy the final adjusted coordinates would meet or exceed the 2nd Order requirements.

The Department of Transportation selected a test course containing 7 stations of known geodetic values. These stations had been previously surveyed by M.D.O.T. and were included in a submission to N.G.S. for final adjustment, inclusion in the N.G.S. archives and the national geodetic network.

These seven stations were in a general North/South and East/West orientation, and M.D.O.T. provided values only at each end and midpoint station. These points were held as fixed, with the test survey to determine coordinates on the intermediate stations, and comparisons of surveyed coordinates versus known coordinates used to determine acceptance/rejection of the survey data. The test was run under circumstances that would closely stimulate actual field conditions, with no considerations given to the traverse route or general layout. See exhibit A for test traverse comparisons.

Field surveys were completed in 45 calendar days from the acceptance of test results.

#### GEOCERTIN ADJUSTMENTS

Geocertin<sup>TM</sup> represents the latest achievement in combining sophisticated computer programs, detailed pre-survey planning, adherence to strict quality control guidelines and the SPANMARK<sup>TM</sup> Inertial Survey System to provide surveys of the highest order. In laying out all of the traverse routes to be surveyed in Michigan special attention was given to existing control locations. Several traverse routes were within existing arc's of geodetic control, while others were forming a major tie between adjoining arc's. The areas where adjoining arc's were being connected, usually required a cross-tie, run in a perpendicular direction to the main traverse routes. These cross ties, in some cases contained new survey monuments, but also provided a strengthening to the overall configuration of the network design. (Exhibit B)

Quality control of traverse data was monitored by utilizing a computer in the field to aid the surveyors decision process in detection and elimination of blunders, malfunctions or unacceptable errors while still on location.

Thereafter computerized adjustment and analysis of all inertial observations and control values in a rigorous least squares adjustment program was completed. Geocertin<sup>TM</sup> allows for independent adjustment of both horizontal and vertical observations, while using either a 'free' adjustment, (Exhibit C) to test the system accuracy or a 'fixed' adjustment (Exhibit D) utilizing the existing control values. Using data output from the previous procedures, an evaluation report provides data on error ellipses for all stations, distances between points and mean azimuth between points. Uncertainty in distance is measured in both meters and parts-per-million at selected stations, thereby permitting the determinations of accuracy ratios. (Exhibit E).

In conclusion the final adjustment of the Inertial Survey observations in Michigan are awaiting the results of the newest data from N.G.S. currently in process. A preliminary report indicates that 96% of all stations meet or exceed the accuracy requirement for 2nd Order Class III control.

EXHIBIT 'A'

△ Reincke

Dist. 1:458,644  
Pos. 1:85,995

RM5 (Held)  
Published - N 503,513.61 E 1,977.926.73

Dist. Pub. 41278.29' Azimuth Pub. 7°57'18.5"  
Sur. 41278.38' Sur. 7°57'20.8"

△ White

Dist. 1:77,354  
Pos. 1:37,603

Published - N 462,632.55 E 1,972,213.91  
Surveyed - N 462,632.53 E 1,972,213.43

Dist. Pub. 27074.59' Azimuth Pub. 20°18'15.1"  
Sur. 27074.24' Sur. 20°18'17.1"

△ Beaumont RM#1

Dist. 1:161,232  
Pos. 1:89,573

Published - N 437,240.28 E 1,962,818.91'  
Surveyed - N 437,240.68 E 1,962,818.31'

Dist. Pub. 64,492.63' Azimuth Pub. 0°04'41.3"  
Sur. 64,493.03' Sur. 0°04'39.4"

△ Dudley (Held)

Dist. 1:52,392  
Pos. 1:46,795

Published - N 372,747.71 E 1,962,730.96

Dist. Pub. 56,060.45' Azimuth Pub. 88°15'26.1"  
Sur. 56,061.52' Sur. 88°15'26.9"

△ Wilson

Dist. 1:80,335  
Pos. 1:76,032

Published - N 374,452.61 E 1,906,696.44  
Surveyed - N 374,452.43 E 1,906,695.36

Dist. Pub. 42,578.27 Azimuth Pub. 86°06'03.4"  
Sur. 42,577.74 Sur. 86°06'03.5"

△ Battle

Dist. 1:69,103  
Pos. 1:69,103

Published - N 371,557.33 E 1,864,216.72  
Surveyed - N 371,557.22 E 1,864,216.17

Dist. Pub. 38,698.38' Azimuth Pub. 73°18'39.8"  
Sur. 38,697.82' Sur. 73°18'39.5"

△ Kidder (Held)

Published - N 360,444.09 E 1,827,148.40

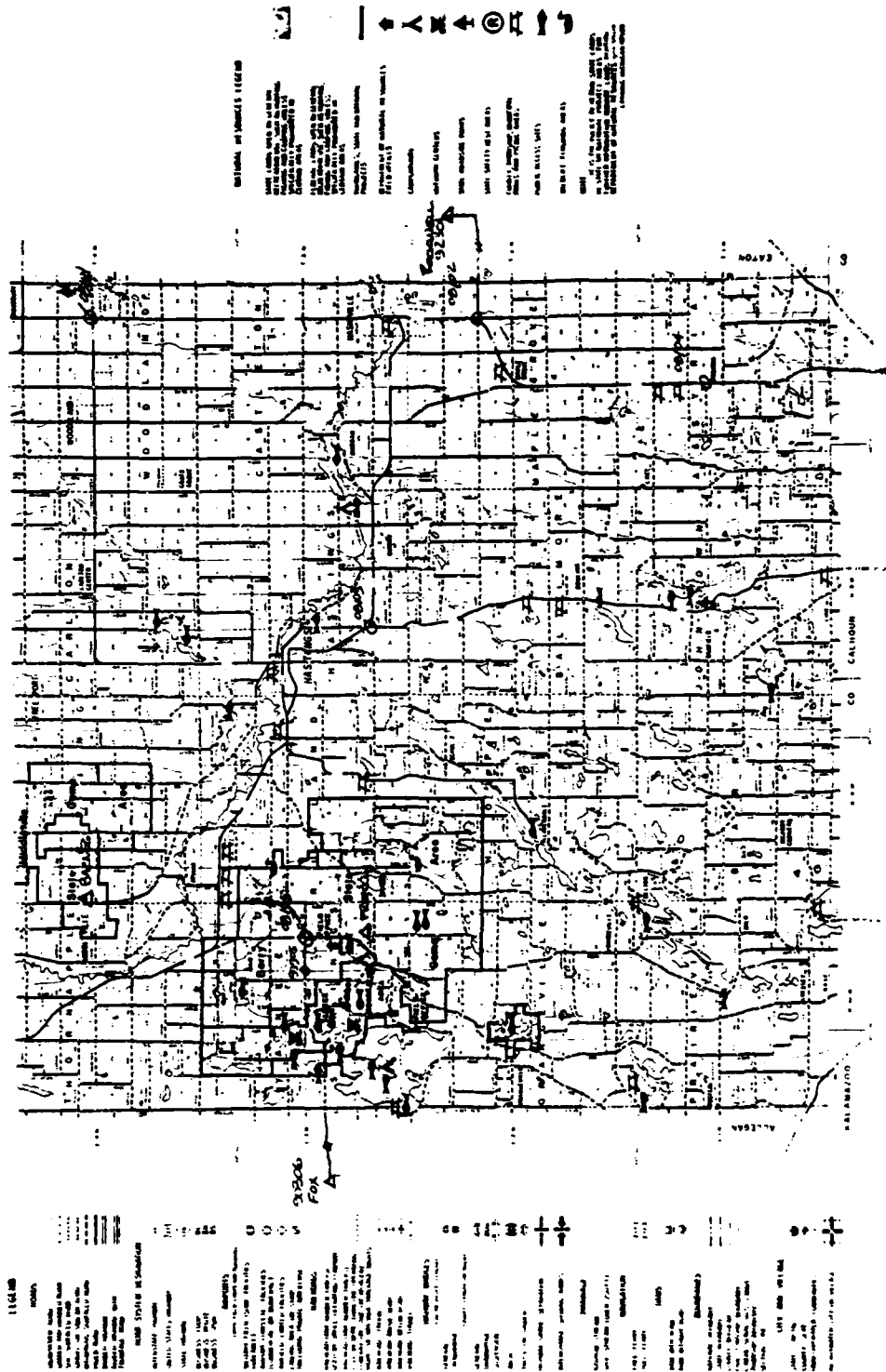


Exhibit B



-----  
M.O.O.T. FREE ADJUSTMENT  
-----

THE ESTIMATE OF THE VARIANCE FACTOR AFTER ADJUSTMENT IS .3910  
THE A PRIORI VARIANCE FACTOR WAS 1.000  
THIS GIVES A VARIANCE RATIO OF .391

2560	DEGREES OF FREEDOM
0	OBSERVATIONS
3622	POSITION EQUATIONS
70.7	PER CENT REDUNDANCY
531	FREE STATIONS
4.8	DEGREES OF FREEDOM PER FREE STATION
1	ITERATIONS REQUIRED FOR CONVERGENCE

THE VARIANCE RATIO TEST IS NOT SATISFIED AT THE 99 ( CONFIDENCE LEVEL  
IN THAT THE RESULTS ARE BETTER THAN THE MATHEMATICAL MODEL INDICATED  
F TEST FACTOR = 2.39  
IT SHOULD BE LESS THAN UNITY

Exhibit C

DATE= 01/09/21

INERTIAL SURVEYING SYSTEM PROGRAM GAMFT

CLARK 1966

M.D.O.T. FREE ADJUSTMENT

INSUFFICIENT VARIATES FOR A CHI-SQUARED TEST OF THE TOTAL SET OF OBSERVATIONS  
THE STANDARDISED CORRECTIONS HAVE BEEN SCALED BY THE CALCULATED SECOND MOMENT. FACTOR = 1.9272  
VALUES GREATER THAN THE VALUE OF TAU ( 1.9600 ) WILL BE MARKED

ICORF	POSITION NUMBER	EQUATION RESIDUALS	GROUP NO	1	IDENTIFIER	353	1	OBSERVED POSITION	CORRECTION	ADJUSTED POSITION
QA	Q2101		42 36	6.31904 N	AS 3A	17.47807 W	.478 S	.478 S	.010 W	42 36 6.32381 W
QA	Q102		42 36	.50503 N	AS 5	43.02708 W	.407 S	.407 S	.375 F	42 36 .50184 N
QA	Q103		42 36	30.55203 N	AS 1A	13.43008 W	.613 S	.613 S	.458 F	42 36 30.53218 N
QA	Q105		42 36	18.30803 N	AS 2A	58.31807 W	.770 S	.770 S	.182 W	42 36 18.47308 N
QA	Q0005		42 36	18.00304 N	AS 2A	17.23507 W	.505 S	.505 S	.020 W	42 36 18.07374 N
QA	Q1004		42 37	12.47304 N	AS 3A	28.55408 W	.687 S	.687 S	.212 W	42 37 12.65078 N
CONTRIBUTION TO THE MINIMUM = 6.5066										
MEAN DISPLACEMENT .010130 S .002023 E RANGE LATITUDE .02406 LONGITUDE .02940										

ICORF	POSITION NUMBER	EQUATION RESIDUALS	GROUP NO	2	IDENTIFIER	353	2	OBSERVED POSITION	CORRECTION	ADJUSTED POSITION
QA	Q0104		42 37	12.47304 N	AS 3A	28.55408 W	.687 S	.687 S	.212 W	42 37 12.65078 N
QA	Q0005		42 36	18.00304 N	AS 2A	17.23507 W	.505 S	.505 S	.020 W	42 36 18.07374 N
QA	Q105		42 36	18.30803 N	AS 2A	58.31807 W	.770 S	.770 S	.182 W	42 36 18.47308 N
QA	Q103		42 36	30.55203 N	AS 1A	13.43008 W	.613 S	.613 S	.458 F	42 36 30.53218 N
QA	Q102		42 36	.50503 N	AS 5	43.02708 W	.407 S	.407 S	.375 F	42 36 .50184 N
QA	Q2101		42 36	6.31904 N	AS 3A	17.47807 W	.478 S	.478 S	.010 W	42 36 6.32381 W
CONTRIBUTION TO THE MINIMUM = 7.288										
MEAN DISPLACEMENT .010628 S .014583 W RANGE LATITUDE .02227 LONGITUDE .03193										

ICORF	POSITION NUMBER	EQUATION RESIDUALS	GROUP NO	3	IDENTIFIER	353	3	OBSERVED POSITION	CORRECTION	ADJUSTED POSITION
QA	Q1004		42 37	12.47304 N	AS 3A	28.55408 W	.687 S	.687 S	.212 W	42 37 12.65078 N
QA	Q102		42 36	.50503 N	AS 5	43.02708 W	.407 S	.407 S	.375 F	42 36 .50184 N
QA	Q103		42 36	30.55203 N	AS 1A	13.43008 W	.613 S	.613 S	.458 F	42 36 30.53218 N
QA	Q105		42 36	18.30803 N	AS 2A	58.31807 W	.770 S	.770 S	.182 W	42 36 18.47308 N
QA	Q2101		42 36	6.31904 N	AS 3A	17.47807 W	.478 S	.478 S	.010 W	42 36 6.32381 W
CONTRIBUTION TO THE MINIMUM = 1.740										
MEAN DISPLACEMENT .002558 N .003189 W RANGE LATITUDE .03109 LONGITUDE .01004										

Exhibit C

CLARKE 1866

M.D.O.T. FIXED ADJ SECOND PASS...TIGHT MODEL

THE ESTIMATE OF THE VARIANCE FACTOR AFTER ADJUSTMENT IS .7518  
THE APRIORI VARIANCE FACTOR WAS 1.000  
THIS GIVES A VARIANCE RATIO OF .752

2812	DEGREES OF FREEDOM
0	OBSERVATIONS
3872	POSITION EQUATIONS
72.6	PER CENT REDUNDANCY
530	FREE STATIONS
5.3	DEGREES OF FREEDOM PER FREE STATION
1	ITERATIONS REQUIRED FOR CONVERGENCE

THE VARIANCE RATIO TEST IS NOT SATISFIED AT THE 99 ( CONFIDENCE LEVEL  
IN THAT THE RESULTS ARE BETTER THAN THE MATHEMATICAL MODEL INDICATED  
F TEST FACTOR = 1.21  
IT SHOULD BE LESS THAN UNITY

Exhibit D

INERTIAL SURVEYING SYSTEM PROGRAM GANET

DATE= 81/09/22

M.D.O.I. FIXED ADJ SECOND PASS...IIGHI MODEL CLARKE 1866

CODE	POSITION NUMBER	EQUATION NAME	RESIDUALS	GROUP NO	182	IDENTIFIER	353	2	CORRECTION	ADJUSTED POSITION
QA	90306			42 37	12.87304 N	85 38	28.55408 W	.001 S	.002 E	42 37 12.87300 N 85 38 28.55400 W
QA	99905			42 38	18.96603 N	85 28	17.22106 W	.207 S	.351 W	42 38 18.98933 N 85 28 17.23647 W
QA	8105			42 38	18.48903 N	85 26	48.30208 W	.038 S	.201 W	42 38 18.48779 N 85 26 48.31091 W
QA	8103			42 36	39.54904 N	85 16	13.37806 W	.208 S	.803 W	42 36 39.54231 N 85 16 13.41330 W
QA	8102			42 34	60103 N	85 5	42.98706 W	.373 S	.675 W	42 34 58895 N 85 5 43.01667 W
QA	92301			42 36	6.33904 N	84 58	32.47607 W	.001 S	.002 E	42 36 6.33900 N 84 58 32.47600 W
										CONTRIBUTION TO THE MINIMUM = 17.03

MEAN DISPLACEMENT .004470 S .014824 W RANGE LATITUDE .01208 LONGITUDE .03532

CODE	POSITION NUMBER	EQUATION NAME	RESIDUALS	GROUP NO	183	IDENTIFIER	353	3	CORRECTION	ADJUSTED POSITION
QA	93904			42 17	34.16003 N	85 30	1.46907 W	.001 S	.002 E	42 17 34.16000 N 85 30 1.46900 W
QA	39102			42 16	48.85203 N	85 20	12.07207 W	.384 N	.184 W	42 16 48.86449 N 85 20 12.08011 W
QA	13103			42 15	59.96304 N	85 10	46.76306 W	.197 N	.251 W	42 15 59.96944 N 85 10 46.77399 W
QA	91301			42 17	52.97602 N	84 59	51.01808 W	.247 N	.195 W	42 17 52.98403 N 84 59 51.02657 W
				42 16	56.97204 N	84 50	8.48507 W	.001 S	.002 E	42 16 56.97200 N 84 50 8.48500 W
										CONTRIBUTION TO THE MINIMUM = 2.817

MEAN DISPLACEMENT .005358 N .005465 W RANGE LATITUDE .01250 LONGITUDE .01100

CODE	POSITION NUMBER	EQUATION NAME	RESIDUALS	GROUP NO	181	IDENTIFIER	353	1	CORRECTION	ADJUSTED POSITION
QA	92301			42 36	6.33904 N	84 58	32.47607 W	.001 S	.002 E	42 36 6.33900 N 84 58 32.47600 W
QA	8102			42 34	59503 N	85 5	43.02708 W	.187 S	.237 E	42 34 58895 N 85 5 43.01667 W
QA	8103			42 36	39.55203 N	85 16	13.43008 W	.300 S	.382 E	42 36 39.54231 N 85 16 13.41330 W
QA	8105			42 38	18.49804 N	85 26	48.30107 W	.316 S	.224 W	42 38 18.48779 N 85 26 48.31091 W
QA	99905			42 38	18.49304 N	85 26	17.23507 W	.114 S	.032 W	42 38 18.98933 N 85 26 17.23647 W
QA	90306			42 37	12.87304 N	85 38	28.55408 W	.001 S	.002 E	42 37 12.87300 N 85 38 28.55400 W
										CONTRIBUTION TO THE MINIMUM = 12.13

MEAN DISPLACEMENT .004972 S .002603 E RANGE LATITUDE .01025 LONGITUDE .02662

Exhibit D

INERTIAL SURVEYING SYSTEM PROGRAM GANET

DATE= 81/09/22

M.O.O.T. FIXED ADJ SECOND PASS...FLIGHT MUEL

CLARK 18066

ELLIPSES BASED ON THE A PRIORI VARIANCE FACTOR = 1.0000 R.A. = 2.45 X SEMI MAJOR AXIS/DISTANCE EXPRESSED IN PPM  
STANDARD ERROR ELLIPSES

STATION FROM	NAME	STATION TO	NAME	DIST (RM)	MEAN AZ (DEG)	MAJ AXIS (M)	SEMI AXIS (M)	SEMI MIN (M)	RATIO AZ MIN/MAJ SEC	AZ M	DIST PPM	R.A. PPM
13	8105	5	90306	16.08	82.77	16.91	.111	.110	1.00	1.42	.111	6.87
		10	90805	10.12	8.58	12.42	.111	.110	.99	2.25	.111	10.97
		11	90806	13.40	16.06	15.78	.111	.110	1.00	1.70	.111	8.28
		27	92301	36.86	96.02	17.68	.111	.111	1.00	.59	.111	2.84
		125	90804	2.34	157.31	17.37	.111	.110	1.00	9.77	.111	47.42
		181	8102	29.92	105.42	86.20	.163	.141	.87	.99	.161	5.38
		182	8103	14.79	101.92	130.45	.159	.158	1.00	2.20	.158	10.71
		184	99905	2.03	90.44	88.77	.073	.072	1.00	7.36	.073	35.84
14	99905	5	90306	14.08	81.67	53.28	.123	.123	1.00	1.80	.123	8.73
		10	90805	10.59	19.29	41.75	.123	.122	1.00	2.39	.123	11.60
		11	90806	14.08	24.02	50.98	.123	.123	1.00	1.80	.123	8.73
		27	92301	40.88	95.75	50.78	.123	.123	1.00	.62	.123	3.90
		125	90804	3.64	126.55	53.71	.123	.123	1.00	6.96	.123	33.64
		181	8102	31.88	104.48	86.17	.174	.152	.88	1.00	.172	5.38
		182	8103	16.78	100.54	115.12	.171	.170	.99	2.10	.171	10.21
		183	8105	2.03	90.44	88.77	.073	.072	1.00	7.36	.073	35.84
15	39102	22	91301	41.33	89.65	177.96	.162	.154	.96	.81	.154	3.74
		23	91302	20.82	49.70	177.97	.161	.154	.96	1.57	.157	7.55
		49	93904	13.58	95.91	177.96	.161	.154	.96	2.45	.155	11.39
		186	13103	13.04	96.64	84.66	.150	.148	.94	2.34	.150	11.50
		187	13101	28.04	85.95	91.22	.226	.212	.94	1.56	.226	8.06
		434	13104	16.59	139.83	49.20	.186	.185	.94	2.31	.185	11.13
16	13103	22	91301	28.43	86.45	13.66	.140	.136	.97	1.01	.136	4.80
		23	91302	15.27	11.11	13.45	.140	.136	.97	1.84	.140	9.15
		49	93904	26.62	96.27	13.57	.140	.136	.97	1.08	.136	5.11
		179	99807	64.17	6.62	20.53	.140	.137	.98	.44	.140	2.18
		185	39102	15.04	96.64	84.66	.150	.148	.94	2.34	.150	11.50
		187	13101	15.42	76.93	90.51	.198	.171	.86	2.31	.197	12.75
		192	99904	43.62	1.61	9.64	.190	.171	.90	.60	.189	4.32
		208	12104	23.23	11.36	2.70	.162	.153	.95	1.36	.162	6.97
		434	13104	11.40	11.46	13.51	.129	.127	.99	2.30	.129	11.28
		434	12102	36.23	7.52	2.61	.100	.100	.99	.129	.129	11.28

Exhibit E

Exhibit E

SESSION X: PHOTOGRAMMETRY



Jack Erlandson  
Seattle District  
Chairman  
(also Speaker)



Jonathan Howland  
Autometric, Inc.



David Nale  
Aerial Data  
Reduction  
Associates, Inc.

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SESSION X  
PHOTOGRAMMETRY

Summary

The session of photogrammetry provided a brief, but valuable picture on the state of art in the field of photogrammetry. Three papers were presented, one on a new instrument and the other two on specific applications. Mr. Jonathan Howland, Autometric, Inc., discussed the new APPS IV or the latest in the line of Analytical Photogrammetric Positioning Systems. Although, originally, developed by Engineering Topographic Laboratory (ETL) as a point positioning device, Autometric has expanded the applications of this medium accuracy, analytical stereo-plotter, to include photointerpretation, measurement of structural deformation, determination of earthwork quantities, checking map accuracy, and boundary surveying to name a few. The second paper was presented by Mr. David Nale, Aerial Data Reduction Associates, who described a photogrammetric and interactive graphic technique for measuring and monitoring beach erosion at Sea Isle City, N. J. This method was a reliable and cost-effective alternative to conventional field surveys. The last paper was presented by Mr. Jack Erlandson, Seattle District, who discussed a large boundary survey project in the State of Washington, where photogrammetry was used to assist the land surveyor in locating, positioning, and restoring lost and obliterated land corners. This project also showed that photogrammetry is a practical and reliable tool for cadastral retracement surveys.

SURVEYING AND MAPPING  
APPLICATIONS OF THE APPS-IV PLOTTER

Jonathan C. Howland  
Autometric, Incorporated  
5205 Leesburg Pike, Suite 1308  
Falls Church, Virginia 22041

BIOGRAPHICAL SKETCH

Jonathan Howland received his B.S. with highest distinction in Surveying Engineering at the University of Maine at Orono. He is currently employed as a Scientist at Autometric, Inc., where he works in new wave photogrammetric techniques. Before starting at Autometric, he worked as a field surveyor in Saudi Arabia. He is a member of ASP, ACSM, Phi Kappa Phi, and Tau Beta Pi.

ABSTRACT

The APPS-IV is an economical, medium accuracy stereoplotter with several unique characteristics. Built in microprocessors allow a great deal of independence from a host computer, and a new stage design allows rapid movement around the imagery. These characteristics, and others, make the APPS-IV easy to use.

Analytical plotters like the APPS-IV have many applications in surveying and mapping. Construction monitoring, volume determination, map checking, and boundary surveying are discussed.

The surveying and mapping applications of the APPS-IV are currently being explored at the U.S. Army Engineering Topographic Laboratory.

APPS-IV DESCRIPTION

The APPS-IV is the latest in a line of APPS systems, which began with the APPS-I, a system developed at the U.S. Army Engineering Topographic Laboratory and built by IDEAS Incorporated. The APPS-IV (APPS is an acronym for Analytical Photogrammetric Processing or Positioning System), produced by Autometric Incorporated, a subsidiary of IDEAS, is a medium accuracy (ten micron RMS) analytical stereoplotter compatible with any computer having an RS-232c interface.

As an analytical plotter, the APPS-IV is able to produce "real world" coordinates from a stereo model. The stereo model can be formed from any imagery which fits on the ten by ten inch stages of the APPS, including standard frame camera, panoramic camera and side looking radar images. Computer programs mathematically correct the coordinates for the distortions inherent in photography, such as atmospheric refraction, earth curvature, film shrinkage and lens distortion. The data compiled by the APPS IV is fully as rigorous as the original phototriangulation or resection which established the orientation parameters. Further, as the operator moves around in the stereomodel, the APPS-IV automatically clears any y-parallax, allowing easy stereo viewing with no burden on the operator. An interesting feature of the APPS-IV is the common stage which carries two separate photo stages.



The common stage can be moved under servomotor control by rotating a trackball or manually by disengaging and slewing it. Thumb wheels allow differential motion of the two stages. Y-parallax removal, or "loop close" remains operational no matter how fast the operator moves the stages.

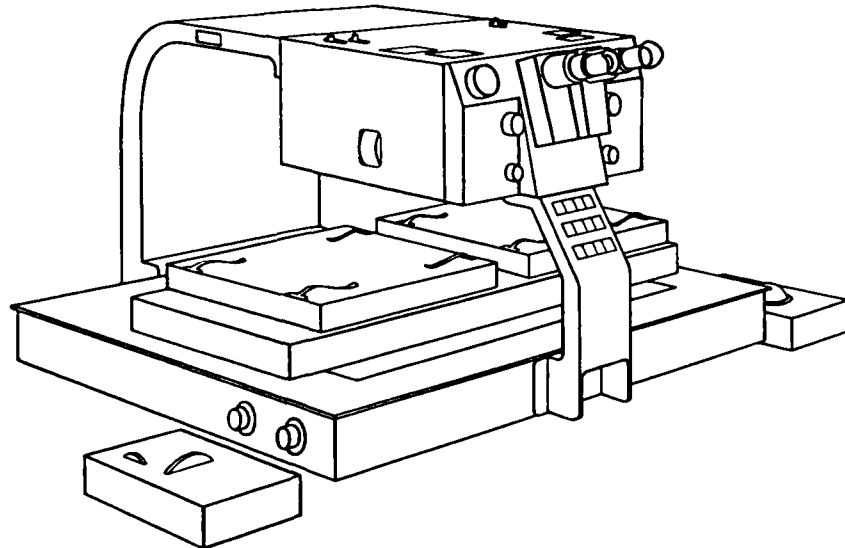


FIGURE I. The APPS-IV Plotter

The principal feature of the APPS-IV is that it places no real time demands on the host computer. Microprocessors housed within the APPS-IV perform all the real time computations previously mentioned. This gives APPS users great flexibility in adapting the system to whatever computer is available. The machine can and does operate on systems as small as an HP-9825 desktop calculator and as large as a DEC VAX 11/780. Autometric supplies custom software for each APPS-IV, addressing the needs of the particular user. Since there is no dependence upon a specific computer, existing user software can readily be modified to interface to the APPS-IV. This machine independence can also reduce the cost of acquiring a system, since a purchaser may already have his own computer.

The basic operation common to all APPS-IVs consists of mounting the imagery on the stages, measuring reference marks and control points, and allowing the host computer to compute the model setup parameters. The computer guides the operator through the set-up procedure with a set of plain English instructions. The unique "stage on stage" design of the APPS-IV permits rapid transit from one area of the imagery to another, and permits quick and easy measurement of any reference marks. After computing the model parameters, the host computer downloads them to the microprocessors in the APPS-IV and the real time computations required to maintain a parallax free stereo model become independent of the host. The entire process takes five to ten minutes, depending upon the speed of the operator (Greve and Niedzwiadek, 1979). With minimal training, a non-photogrammetrist could use the APPS-IV in all the applications that will be mentioned in this paper.

## APPLICATIONS

Currently, the APPS-IV is used most often in targetting and photo-interpretation, but it has many applications in surveying and mapping. Some of these photogrammetric applications have been discussed in the literature for years, but have only recently become practical with the advent of economical analytical plotters. The U.S. Army Corps of Engineers is currently exploring the potential of the APPS-IV in surveying and mapping at the Engineering Topographic Laboratory.

Analytical photogrammetry offers special abilities in the monitoring of construction, especially when using terrestrial techniques. Plotters like the APPS-IV can handle non-metric and convergent photography, of any focal length and image format. Analog plotters can rarely reduce these kinds of imagery, due to optical-mechanical limitations.

The use of non-metric cameras has several attractive advantages over the use of metric cameras. Non-metric cameras are readily available and relatively inexpensive. They offer a wide focussing range and can be hand held and readily pointed in any direction. These advantages are countered by high distortion, a lack of fiducials, and frequent instability in orientation. A further drawback common to all terrestrial photogrammetry is that atmospheric refraction close to the ground is often unpredictable and is more difficult to model than the atmospheric effects encountered in aerial photography. Nevertheless, recent research indicates that terrestrial photogrammetry, even using non-metric cameras, is capable of producing high precision results (American Society of Photogrammetry, 1979).

If multiple cameras are used, photogrammetric techniques can capture a "snapshot" of a process, and obtain the three dimensional positions of many points at one instant in time. This technique is frequently useful in monitoring construction projects and measuring structural deformation. Analytical plotters are particularly suitable for this type of work, since they retain the capability of detailed mapping with high accuracy while the rapid model reset capability also makes it feasible to measure the positions of only a few points.

Another engineering application of analytical plotters is the photogrammetric determination of earth volume. The engineer can use these earth volumes to determine contractor excavation quantity payments (a technique currently used in the Seattle District by the U.S. Army Corps of Engineers and accepted by both contractors and the Government) and in predicting cut and fill quantities. Volume determination is a relatively simple and straightforward process. While the operator keeps the floating dot on the surface of the ground, the APPS-IV automatically drives it along a profile. The resulting set of parallel dense profiles will form an accurate digital elevation model (DEM) of the area. Standard techniques are readily available to compute volumes from a DEM. By comparing volumes from a current DEM with those obtained at an earlier date, an accurate measurement of the amount of earth removed by an excavation contractor can be obtained (Dodge and Holmes, 1979).

The calculation of cut and fill from profile and cross section data is standardized within the engineering industry. Photogrammetric techniques greatly reduce the time and effort needed to obtain the profiles and cross sections with comparable results. Photogrammetric methods are considerably cheaper, easier, and safer than conventional ground surveys.

Another prime use of an analytical plotter like the APPS-IV is the rapid checking of map accuracy. The ability to rapidly reset a model makes the measurement of a relatively small number of points practical. It is easy to envision techniques for measuring a point on a questioned map and having the APPS-IV drive to the point on the imagery used to produce the map so the operator can take a static elevation measurement. A number of these measurements could be taken and compared analytically to map measurements. The comparison would rapidly produce an estimate of both the vertical and horizontal accuracy of the map. The ease and efficiency of methods like this allows the use of statistically defensible accuracy references (Loon, 1981). An APPS-IV interfaced to a standard compilation package could also be used to produce a map, allowing a visual estimation of map accuracy. The use of analytical plotters in standard mapping greatly increases production, due to reduced model set-up times and the ability to use smaller scale photography while retaining map accuracy (Robinson, 1979).

Analytical plotters also provide a means to determine the ground position of property corners. If it becomes necessary to stake out a boundary in a remote or inaccessible location, the stages of an APPS-IV could be driven to a desired corner's image on existing photography. The plotter operator could find several identifiable offset points in the area, and the necessary distances and azimuths to the corner could be computed easily. A field party could travel to the area by the easiest method, and stake out the corner without having to survey it in over long distances.

Several of these tasks could also be accomplished on an analog plotter or comparator, but the procedures would be much more difficult. Cost comparisons are difficult, since many applications of analytical photogrammetry are impractical when performed conventionally, allowing no basis for comparison. It is important to emphasize again that although the analytical techniques may involve rather sophisticated mathematics and electronics, the complexities are transparent to the stereoplotter operator. He can achieve reliable results with minimal training and skills. Analytical photogrammetric plotters and techniques offer great potential to today's surveying agencies and firms. The flexibility of the computer software safeguards plotters like the APPS-IV against obsolescence in the future.

#### REFERENCES

- American Society of Photogrammetry, 1979, Handbook of Non-Topographic Photogrammetry, Falls Church, VA.
- Dodge, R.K. and Holmes, S.K. 1979, "Bonneville Dam Second Powerhouse Photogrammetric Cross Sections for Excavation Contractor Payments," Proceedings of the U.S. Army Corps of Engineers Remote Sensing Symposium, October 29-31, Reston, VA. pp. 277-78.
- Greve, C.W., Niedzwiadek, H.A., Bunn, R. and Walsh, B. 1979, "Current and Potential Applications of the APPS-IV Analytical Plotter." Proceedings of the American Society of Photogrammetry, March 18-24, Washington, D.C. pp. 80-86.
- Robinson, J. 1980, "Chicago Aerial Surveys' Experience with the Zeiss Planicomp C-100," Proceedings of the Analytical Plotter Symposium and Workshop, April 20-25, Reston, VA. pp. 181-89.

## PHOTOGRAMMETRY IN BOUNDARY SURVEYING

John P. Erlandson  
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Seattle, Washington 98124

### BIOGRAPHICAL SKETCH

Jack Erlandson graduated from the University of Washington in geography, with a specialization in cartography. Since 1961, he has been employed by the Seattle District, in various capacities, most recently as Chief of the Survey Branch. In this position, he is responsible for all land surveys, photogrammetric mapping, and remote sensing activities performed by the district. He is a member of ASP and ACSM.

### ABSTRACT

Traditional field survey methods for cadastral retracement and boundary surveys are difficult and costly in rugged and inaccessible terrain. Photogrammetry provides the land surveyor with a means to obtain reliable, accurate and inexpensive measurements for this work. Procedures used by the Seattle District to establish the project boundary (property acquisition line) on the Chief Joseph Dam and Reservoir Project are discussed. An estimate of savings in survey costs are made and the results of field checks are shown.

### INTRODUCTION

The Chief Joseph Dam Project is located on the Columbia River, in the north-central part of the State of Washington. The dam was constructed between 1950 and 1958 to produce power. In 1973, new construction began to raise the height of the dam and reservoir by 10 feet and install additional generating units. This work was completed in 1979. The present dam rises 236 feet above the original streambed and creates a reservoir 51 miles in length.

The new construction and subsequent pool raise necessitated the acquisition of additional property and the monumentation of a new project boundary. Before locating the boundary, a complete cadastral retracement survey was required to prepare accurate legal descriptions. Previous survey and real estate information, obtained during initial construction, was insufficient.

### EARLY PLANNING

Preliminary planning for the survey began in the spring of 1974. The work requirements were defined and consisted of a search for existing land corners, ties to the state plane coordinate system and calculation and restoration of lost and obliterated corners. Under normal conditions this work would be accomplished entirely by field survey methods. However, considering the size of the project, the rugged terrain and lack of ready access to many areas of the reservoir, less costly methods were examined. After a thorough evaluation, photogrammetry was selected to obtain the positions of the land corners. This decision was based primarily on the success of similar work performed by others. It had been proven that the use of photogrammetry would not only satisfy Bureau of Land Management (BLM) and state standards, but also significantly reduce costs in a cadastral retracement.

## PROCEDURES

Survey Control. One factor affecting the accuracy of any photogrammetric survey is the distribution and accuracy of the survey control. Fortunately, reasonably good control existed throughout the project area. In 1967, traverses were established on both banks to satisfy photo control requirements, for topographic mapping. A review of the methods and procedures used in this work indicated that some field work would be required to assure that the control satisfied 3rd Order standards. This was accomplished by adding more cross ties between the traverses and more field ties to National Geodetic Survey (NGS) control. The result of this effort was a basic control network having 2nd Order closures.

Initial Field Reconnaissance. When the control surveys were completed, reconnaissance teams began the search for land corners (section and 1/4 corners only), using Government Land Office (GLO) notes and other reference data. Work started at the dam and progressed upstream, on both banks, simultaneously. The result of this effort was 208 found corners and 244 unfound corners.

A target was placed on each found corner and two targets (with rebars) set in vicinity of unfound corners. It was our intent to use one of the two targets as a backsight for restoring the unfound corner after the photogrammetric measurements and corner calculations were completed. In addition, targets were also placed on the photo control points. Altogether, over 700 targets were set and subsequently measured by photogrammetry. Targets were white circles printed on a 40-inch by 40-inch black cloth. The diameter of the white circle was 26 inches or slightly larger than the 40 micron measuring mark in the photogrammetric instrument (at negative scale). To assist the photogrammetrist in locating the target, 5 feet strips of plastic, 6 inches wide, were placed diagonally at each corner.

Aerial Photography. It was determined in the planning stages that the photogrammetric system should be designed to achieve accuracies of  $\pm 1$  foot in the positions of the land corners. This would amply satisfy the BLM cadastral requirement of 1:2000 for rural areas. Using the rule-of-thumb that analytical aerotriangulation could provide accuracies in the neighborhood of 1:10,000 of the flying height, the decision was made to fly at 6000 feet to assure that the results would be better than 1 foot. The photography was flown in black and white, using Wild RC-8 and Zeiss RMK A 15/23 aerial cameras. The project was divided into five convenient blocks, each having at least five strips, with 60 percent overlap between exposures and strips. The blocks were flown sequentially, starting at the dam and progressing upstream as the field teams completed the targetting. All photography was flown in the summer and fall of 1974.

Aerotriangulation. Photography used for aerotriangulation was printed on glass diapositives. Most of the tie point requirements for strip and block assembly were satisfied by the high density of uniformly spaced targets. Artificial points were added in the gaps using a Wild Pug IV point transfer device.

All photographic measurements were made on a Wild A-7 Autograph. A sequential or polynomial adjustment was used to determine the position of each target on the ground. Because of the magnitude of data and the program and storage limitations on the computer (IBM 360-70), the blocks could not be tied together. Each block was separate adjustment to itself.

To assure project continuity, ample overlap was provided between blocks for checking the dual coordinates of common points. The total project consisted of 350 stereo models. The horizontal residual error or the best photographic fit to the ground control points was 0.55 feet which slightly exceeded expectations. The average difference between coordinates of points falling within the overlap portion of blocks was 0.81 feet. The coordinates of these points were meaned for the calculation process.

Second Field Reconnaissance. A review of the initial reconnaissance and found land corners on the photography revealed that the field teams were occasionally looking for corners that were some distance away from their most probable location. This occurred when they had projected a considerable distance from the last found corner. Since there was a possibility that more corners existed in the area, another search was initiated.

Using enlarged photographs showing the found corners and the protracted locations of the unfound corners as a guide, the teams found 34 more corners. Since the photography had already been flown, the new found corners were tied to the basic control. using conventional field survey techniques.

In addition, and after discussions with land owners, twelve fence corners were accepted as land corners. Since the fence corners were visible on the photography, they were measured on the A-7 and incorporated into the final adjustment.

Calculation of Missing Corners. Coordinates of missing or destroyed land corners were calculated by conventional proportioning methods, using the GLO notes and the photogrammetric positions of found corners. The coordinates for these corners were subsequently provided to the land surveyor for restoration and monumentation.

Restoration and Perpetuation. Only missing section and 1/4 corners lying immediately outside of the project boundary (115) were restored and monumented. In addition, each corner was perpetuated by placing a fence post in the immediate vicinity. During restoration, six more land corners were found. This necessitated a field survey tie and recalculation of the missing corners in the affected and adjacent section(s).

## RESULTS

Field checks were made to 37 randomly selected corners by bearing and distance from the basic control. Eleven of the checks were "stub" shots with no built-in check on their accuracy. The standard error of the checked corners was  $\pm 1.06$  feet or slightly more than anticipated, but still within BLM standards for rural areas. Subsequent checks during the monumentation of the project boundary provided similar results.

## SUMMARY

The cadastral retracement and restoration of missing land corners was completed in December 1976 or 2-1/2 years after the initial field reconnaissance. Since that time and as funds became available, work has continued with monumenting the boundary. As of this writing, the project is about 75 percent complete and scheduled to be finished before the end of this fiscal year.

Accurate records of costs were not maintained for a comparison of the field and photogrammetric methods. However, the contract surveyor who accomplished most of the field work and who had considerable experience in cadastral surveys stated that the cost of the retracement would have been at least twice the actual cost if conventional field survey methods had been used. Similar savings and more have been substantiated by others who have used photogrammetry for this type of work.

This project shows that photogrammetry is a practical and reliable means to determine the position of land corners to a degree of accuracy suitable for use in rural areas. It was successful because of good planning and coordination between the land surveyor and the photogrammetrist.

PHOTOGRAMMETRIC BEACH MAPPING AND MONITORING  
USING INTERACTIVE GRAPHICS FOR PLOTTING CROSS SECTIONS  
AND VOLUME COMPUTATIONS

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BIOGRAPHICAL SKETCHES

David K. Nale is a Certified Photogrammetrist and Executive Vice President of Aerial Data Reduction Associates, Inc. He received his degree in Earth and Mineral Sciences from The Pennsylvania State University and will shortly complete studies for his Masters in Business Administration from LaSalle College. He has been project manager of a number of major environmental, industrial and political mapping projects. He is president of the Council of Practicing Photogrammetrists, and a Director of the North Atlantic Region of the A.S.P., as well as a member of ACSM and several State survey organizations.

Carl Totten is a Land Surveyor, licensed in New Jersey, Pennsylvania and Maryland. He has been practicing in the private sector since 1961 with major interests in property surveying and control surveys in support of hydrographic and photogrammetric mapping. He serves as a member of the Survey Standards Committee of the New Jersey Society of Professional Land Surveyors and is a member of ACSM.

Val Gannotti, is President of Design Graphics, Inc. He has over 31 years experience in engineering, and is one of the nation's leading proponents of using Interactive Computer Graphics.

Gannotti joined United Engineers as a Project Design Supervisor, responsible for the design of chemical, industrial and nuclear power plants. In 1974, Val left United Engineers as a Nuclear Design Manager to take over the job of Quality Control Manager with the Engineering and Construction Division of Day & Zimmermann, Inc. He later established the Compudraft (Interactive Computer Graphics Service) Division of D&Z, and left the firm in 1980 as President of Compudraft and Vice President of the Engineering & Construction Division.



#### ABSTRACT

Sea Isle City is located along the Southern New Jersey Coast, approximately 20 miles south of Atlantic City.

The Town is a small barrier island community having about 4.7 miles of beachfront on the Atlantic Ocean. The Town's major economic resource is the summer resort trade.

A timber bulkhead and stone revetment serves as protection from tidal erosion for approximately 1.5 miles along the heavily populated, commercial portion of the Town, the remainder relying upon natural and manmade dunes.

Occasional storms have severely eroded the beaches and in certain areas the dunes have been breached and in some cases destroyed.

In the past, several attempts have been made to reconstruct and repair the dunes using materials trucked from mainland sources, and on at least one occasion, a major hydraulic fill operation was performed to restore the recreational as well as protective quality of the beach.

#### INTRODUCTION

The proximity of Southern New Jersey beaches to the major metropolitan centers of the northeast has caused the area to become a favorite summer tourist attraction. The maintenance of the beach consequently is of enormous importance to the economic well being of the resort communities.

To counteract the erosional effects of coastal storms and long shore current, Sea Isle City would undertake beach surveys on a regular basis to determine the volume of sand displaced and would subsequently contract for beach replenishment and regrading.

The beach survey itself has been accomplished by traditional survey cross section methods over the years. These methods were both time consuming and costly. In the Fall of 1980, the City Engineer considered the possibilities of utilizing precision photogrammetric methods to aid in the survey process.

Since the beach survey must be accomplished again and again over the years, it was of prime consideration to design a photogrammetric approach that would be economical, quick and above all, accurate. Considerable importance was given to the repeatability of the methods.

## AERIAL PHOTOGRAPHY

A major problem faced by the land surveyor employing traditional field survey methods was surveying as much of the beach as possible, at low tide. The weather and the seas as well as time of day seldom cooperated with a low tide. Aerial photography, however, permitted a means of accurately recording beach conditions at precisely low tide for miles of beach within seconds under optimal conditions.

Tide charts were employed to target the most desirable days for flying, i.e., days which low tide occurred at the highest sun angle (between 1100 and 1300 hours E.S.T.) A series of possible flying days were selected with the actual flying day to be chosen dependent on weather and visibility conditions.

At precisely 12:00 P.M. on the afternoon of November 20, 1980, a twin-engine Cessna 320 was aligning itself on a pre-determined flight path over the beaches of Sea Isle City, New Jersey. Between 12:01 P.M. and 12:03 P.M. (Mean Low Tide) the entire 4.5 miles of beach was photographed, utilizing a Zeiss RMK A 15/23 mapping camera. The flight altitude was 1800 Ft. above MSL and the film utilized was Kodak Double X Aerographic Film. Standard 60% forward lap stereo photographs were obtained.

## GROUND CONTROL SURVEYS

To obtain numerous field survey locations for photogrammetric control along a terrain as dynamic as a beach is to say the least a formidable undertaking. The normal number of ground control survey points had to be reduced, especially along the water's edge. Permanent control stations were easily established away from the beach along coastal streets. Canterlevering of control was undesirable, however, and some vertical control survey was mandatory at the water's edge. To reduce the number of control points required, analytic aerotriangulation was employed.

Four foot by four foot white targets were painted on coastal streets and available jetties several days prior to the photographic mission. On the morning of the flight, plywood targets were positioned at nine locations on the beach itself.

A problem unique to this type of survey is that these temporary points must be located during the time of low water. It is essential that communications be maintained between the survey party and the flight crew to be sure that targets can be placed and located horizontally and vertically, and the flight made almost simultaneously.

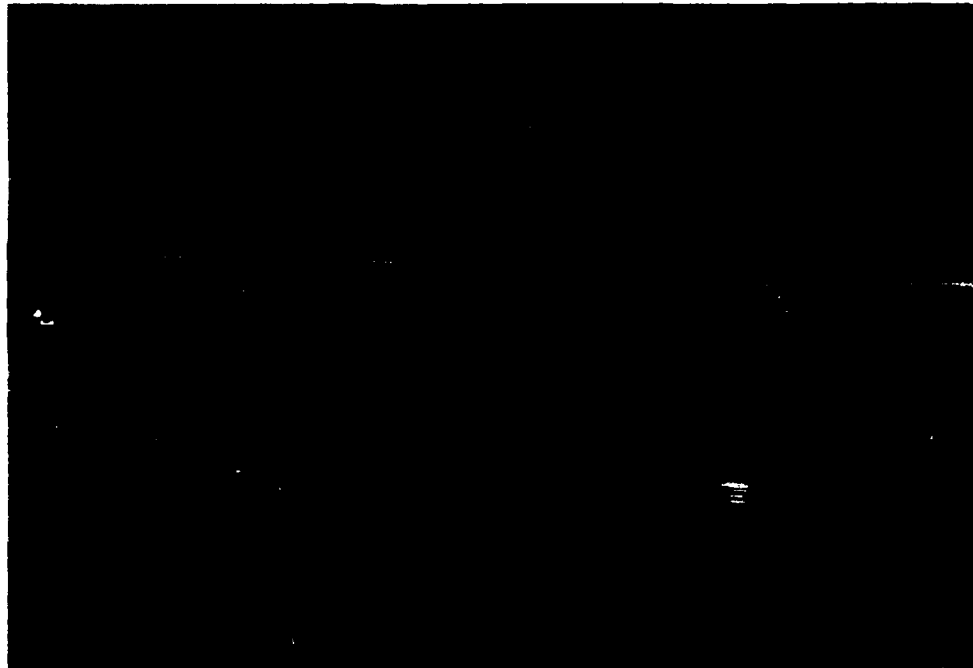


Figure 1: Ground Control Surveys

The New Jersey System of Plane Coordinates and the National Geodetic Vertical Datum of 1929 were chosen as a basis for control of the mapping.

A primary traverse was run between existing first order triangulation stations at the extremities of the project area. Since no azimuth marks were visible from either of these stations, separate polaris observations were performed to provide a starting and closing azimuth. These astronomic azimuths were subsequently converted to New Jersey grid. From this primary traverse, which included as many photo control points as possible, supplementary loops were made to include the remaining points. All traverse procedures were carried out in a manner consistent with Third Order Class I Specifications as set forth by the National Geodetic Survey (Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys). A Wild T1 theodolite and Precision International Beetle 1600S EDM1 were utilized.

Vertical control was extended from a single first order bench mark which was nearly centrally located. A loop was run to each end of the project area and supplementary bench marks established along these routes. Any photo points not included in the primary loops were subsequently tied to these supplementary bench marks.

The computations for horizontal positions were reduced to New Jersey Grid by applying the appropriate scale factors. The reduction of measured lengths to sea level were neglected since the maximum elevation of any station did not exceed eighteen feet.

Perpetuation of the survey control is of utmost importance, and wherever possible, points have been permanently referenced, providing for quick recovery or resetting. This allows for an economical means of re-photographing the area for subsequent erosion monitoring.

#### ANALYTIC AERO-TRIANGULATION

Because of the unique characteristics of a beach survey, analytic aerotriangulation was essential to the successful, swift and economic completion of this project. Ground control targets had to be positioned as close to the water's edge as possible at low tide. Analytics was utilized to reduce the number of these targets to a minimum while at the same time permitting the creation of a significant number of analytic generated control points along the water's edge.

Wild Pug 3 and Pug 4 point transfer devices were utilized to create and transfer analytic control points on 0.13 inch glass diapositives. The pugged control positions were measured on a Kern MK-2 Mono-comparator and their positions simultaneously recorded onto standard 80 column key punch cards. This information was input into a DEC PDP 11/44 computer. The operative analytic aerotriangulation program was John Kenefick's RABATS.

#### STEREO PHOTOGRAMMETRIC COMPILATION AND CROSS SECTIONING

The photogrammetric mapping and cross sections were compiled on a Kern Pg2-AT stereo restitution instrument equipped with a PS2-EO-AT cross section bar and interfaced to a Kern ER-34 Digitizer. The mapping was compiled at the scale of 1" = 50' ( 7X over negative scale) with contours compiled at a 1' interval (See Figure 2).

Cross section data was compiled with 100 foot stationing and 25 foot and breaking grade offsets. All offset points were automatically recorded with offset distances and sea level vertical elevations. The Kern ER-34 Digitizer was interfaced to an IBM 0-29 Keypunch for swift automatic recording of this information onto data cards.

# BEACH IMPROVEMENT

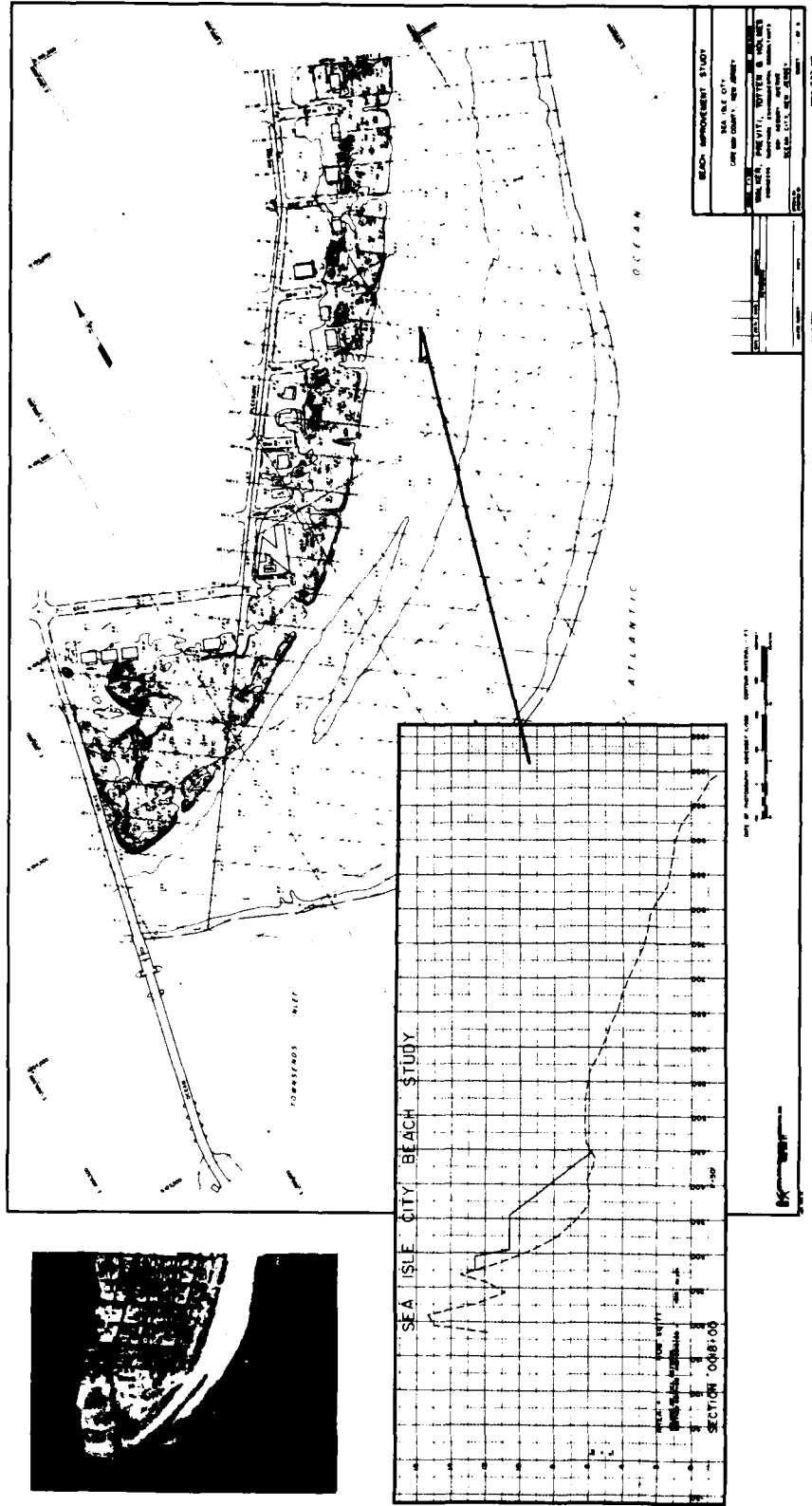


Figure: 2

## INTERACTIVE COMPUTER GRAPHICS, VOLUME CALCULATIONS

The New Jersey Department of Environmental Protection provided the Town Engineer with a template for the fill and grading of the beach (See Figure 3). This template was digitized and placed into the data base.

Design Graphics, Inc. (Philadelphia) received positional and elevation data for the Sea Isle City Beach in the form of punched cards. The firm, which is essentially a computer graphics service bureau, converted the data to magnetic tape for input to a Computervision Designer System and CADD3 computer graphics software.

Design Graphics wrote a computer program in Fortran which had the following purposes:

- To develop a multi-layered drawing within the computer database, where the layers represented consecutive beach elevation drawings at 100-ft intervals.

- To superimpose on each elevation drawing a template representing the desired beach elevation.

- To calculate the cross sectional area in square feet between the template and actual beach elevation for each drawing.

- To machine plot desired elevations with template, including notes on area and volumetric calculations.

The positional reference was at the center of a road that paralleled the beach. Each elevation section was taken perpendicular to the road. Plotting scales selected were 50 ft/inch along the horizontal and 2 ft/inch for elevations. The length of the beach surveyed was about 22,000 ft., so the computer data base contained about 220 elevation drawings in separate memory layers, all of which were actually plotted.

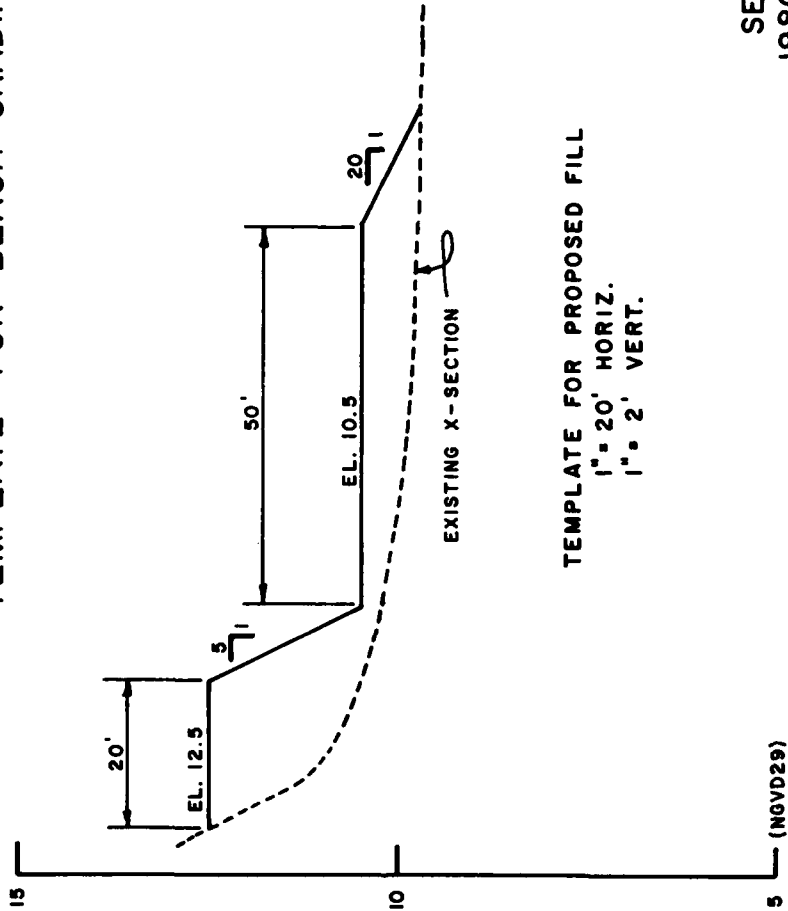
Once the program created the beach elevation section drawings within the computer data base, it superimposed a template for each section, according to the following rules:

- Each template started at the 12.5 ft. elevation of beach nearest the water.

- It continued along a horizontal line towards the water for 20 ft. and then fell off at a slope of 1:5 until the 10.5 ft. elevation point.

- At this point it continued again along a horizontal line towards the water for 20 ft. and then fell off at a slope of 1:20. This slope continued until it intersected with the existing beach elevation.

# TEMPLATE FOR BEACH GRADING



TEMPLATE FOR PROPOSED FILL  
 1" = 20' HORIZ.  
 1" = 2' VERT.

SEA ISLE CITY  
 1980 BEACH SURVEY  
 17 DEC. 1980  
 C.T.

Figure: 3

Some trial-and-error approaches were taken in making the program work to fit actual conditions of a shifting baseline (the road), curves in the beach front, and the existence of low beach areas like the boardwalks at Sea Isle City.

For example, in some cases the beach never reached the 12.5 ft. starting point for the template. If this happened, the program started the template on a line that connected the 12.5 ft. elevation points on beach sections that bracketed the section in question. Once it determined the starting point, the program drew a back slope down to the existing beach, creating in effect, a sand dune. From the artificially created 12.5 ft point it continued the template in the prescribed manner.

The computer graphics approach provided accuracy and consistency in applying the templates to the beach elevations. It also automatically calculated the fill necessary between sections, printing this figure on high quality plots for each section. Finally, it saved time in plotting results. The major time in developing the plots was in writing the program to convert the positional data to the desired computer graphic data base with templates. Once this program exists, however, it greatly simplifies future work along the same lines.

#### CONCLUSION

The photogrammetric mapping and computer volume generation of Sea Isle City's beach was accomplished thru a unique combination of sophisticated State-of-the-Art procedures. Each one a critical link leading to a very successful methodology for beach monitoring. Of equal importance to all that has been heretofore presented is that the beach of Sea Isle City is now permanently recorded in a computer data bank. Ground control survey positions have been permanently established. A simple retargetting of control, a new aerial flight and transfer of analytic control points would permit future monitoring of the beach to be completed even more economically and faster than the first time.

Because the beach has been recorded onto magnetic tape subsequent beach observations can be easily compared inter-actively. A dynamic procedure has been utilized to measure one of the most geologically dynamic features of the earth's surface.



SESSION XI: MONITORING STRUCTURES



Ken Robertson  
ETL  
Chairman  
(also Speaker)



Steve Johnson  
Virginia Polytechnic Institute  
and State University



Darrell Martin  
Walla Walla District  
(No Paper)

SESSION XI  
MONITORING STRUCTURES

Summary

Three papers were given during this session which was devoted to surveying techniques and instruments for use in precise monitoring of dams.

Mr. Steve Johnson of Virginia Polytechnic Institute and State University has developed an adjustment and appropriate computer programs for data taken during dam surveys. He reported the results of the adjustment of several sets of data taken during surveys of Gathright Dam in the Norfolk District.

Mr. Darrel Martin of the Walla Walla District discussed results of their surveys of Dworshak Dam.

Mr. Ken Robertson of the Engineer Topographic Laboratories discussed how precise measurements of tilt could be made with a modification of an automatic level.

PRECISE DEFORMATION SURVEYS OF EARTH DAMS USING  
TRILATERATION AND TRIANGULATION TECHNIQUES

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Steven D. Johnson is Assistant Professor of Civil Engineering at Virginia Polytechnic Institute and State University where he teaches surveying and photogrammetry. He received his degree in Civil Engineering from the University of Wisconsin, Madison. His research interests are primarily in the areas of adjustment computations and analytical photogrammetry. He is a member of ASP, ACSM, Chi Epsilon, and Sigma Xi.

M. K. Miles is a civil engineering graduate of Virginia Polytechnic Institute and State University. Since graduation in 1971, he has been with the Army Corps of Engineers. He has served as Assistant Chief of the Survey Section, Norfolk District until recently becoming the coordinator of surveying and mapping activities at the Office, Chief of Engineers, U. S. Army in Washington, D. C. Mr. Miles is a member of ACSM, SAME, and a Professional Engineer in Virginia

Laura N. Voelker is a Master of Engineering degree candidate in the Department of Civil Engineering at Virginia Polytechnic Institute and State University. Her studies have emphasized analytical photogrammetry and geodesy. She received a B.A. degree in economics and cartography from Vassar College in 1978. Ms. Voelker is a member of ASP and ACSM.

ABSTRACT

The use of trilateration and triangulation survey methods to monitor horizontal displacements in earth dam structures is investigated using two project data sets. The data for the Gathright Dam Project is provided by the Norfolk, Virginia office of the U.S. Army Corps of Engineers. The Gathright Dam survey employs only trilateration measurements. The second data set including both angle and distance measurements on the Logan-Martin Dam Project is

provided by the Alabama Power Company. Both projects employ repetitive surveys to determine shifts in dam surface monuments relative to fixed control.

The design of the total survey system is discussed including instrumentation, survey methods, and data adjustment. The trilateration data is adjusted by a simultaneous least squares adjustment that incorporates a scale-error model to account for atmospheric effects on the EDM measurements. The adjustment results validated the design of the survey system and the scale error modelling technique.

#### GATHRIGHT DAM PROJECT

The Gathright Dam Project is located within the Gathright Wildlife Management Area in the Alleghany Mountains of west central Virginia. The dam was begun in 1969 and completed in 1978. Filling of the Lake Moomaw impoundment to a maximum depth of 152 feet and length of 12 miles was begun in December 1979. Full pool may not be reached until the end of 1981 due to drought conditions. The dam is a rock fill structure with an impervious earthen core. It is 1310 feet long and 257 feet high.

Instrumentation to monitor the Gathright Dam consists of several below surface systems measuring pore water pressure, seepage, and strain within the structure, plus a system of surface monuments that were used to measure horizontal and vertical dam movements. The purpose of this paper is to discuss the surface instrumentation program only and report on the movements determined by precise survey methods. The surface instrumentation surveys were begun in 1973 during construction of the dam. The surveys have been repeated on a regular basis through the construction phase and up to the present time during the pool filling phase. Eight surveys of the total system of monuments have been made starting in July, 1978 and ending in March, 1981. In this paper, we report on five of those surveys. The Gathright Dam monitoring program will be continued beyond the March, 1981 survey.

#### GATHRIGHT HORIZONTAL SURVEYS

The surface monuments used to monitor movement in the dam structure consist of concrete cylinders 12 inches in diameter and imbedded in the dam to a minimum depth of 5 feet. The dam monuments are observed from a group of concrete control pillars 12 inches in diameter. The pillars are set on pedestals to a depth of 8 feet, or they are set down to the bedrock on the gorge walls adjacent to the dam. The control station pillars are approximately 4 feet tall and are protected from disturbance by an 18-inch diameter corrugated metal sheath around the pillar and extending down to the base of the pillar.

The survey configuration locating dam movement monuments is shown in Figure 1. Stations numbered 1 through 34 are monuments on the dam, except monuments 13 through 16 which are in a potential slump area on the north side of the

gorge. Monuments 21 through 34 are on the dam crest. Monuments 1, 2, and 3 are on the upstream side of the dam just above pool elevation. Monuments 9 through 12 are on the downstream side of the dam. Control stations are numbered 41 through 50. The survey configuration locating control monuments is shown in Figures 2 through 6. Station 50 is located near the outlet stilling basin at the base of the dam. Since station 50 is judged to be the most geologically stable monument, it is held fixed in all surveys. The orientation of the control survey is defined by a fixed azimuth mark, number 49, approximately 2.8 miles southeast of the dam.

Procedures. Since the surface instrumentation surveys began in 1973, it has been standard procedure to resurvey the entire horizontal control network every time monitoring surveys are made. This has proved very beneficial as the pillar control monuments are not as stable as originally hoped. Control monument positions are computed with each survey relative to fixed stations 49 and 50. Systematic movements totaling a maximum of 0.07 ft (4.3 mm) have been charted for those pillars from which movement monuments are observed.

The original horizontal monitoring plan for surface movement points employed triangulation to survey the control network and angle intersections to survey the movement stations. Surveyed at night with a Wild T-3 Theodolite and lighted targets for precision and repeatability, the first few surveys proved to be very time consuming and costly. The development and marketing of accurate short range electronic distance measuring instruments (EDMI) proved to be the solution which saved time and money. A comparison of triangulation and trilateration with short range EDM can be found in Wolf and Johnson (6).

Equipment. The first EDM used was an HP 3800 with error specifications of  $\pm 0.02$  ft  $\pm 10$  ppm. The second EDM used was a K & E Ranger III with error specifications of  $\pm 0.02$  ft  $\pm 2$  ppm. The EDM presently being used is an HP 3800 with a calibration cap designed and built by the Instrument and Equipment Branch of the National Geodetic Survey. This instrument has error specifications of  $\pm 0.02$  ft  $\pm 7$  ppm, but when used properly with the cap, gave better and more reliable results than the K & E Ranger III. The calibration cap fits over the objective optics of the EDM. It reflects, via right angle prisms, the output signal immediately back into the input optics. The cap provides a fixed reference distance that is measured frequently during the survey to monitor the electrical center offset error of the EDM.

A unique system of positive centering has also been developed for mounting the EDM on the pillar control monuments and for mounting corner cube retro reflectors on the surface movement points. The centering devices are permanently set in the concrete monuments. They assure the repeatability of measurements to the same point from survey to survey.

Data Reduction and Adjustments. All observed distances are reduced to a spheroid distance using the difference in elevation between the end points of the slope measurements. Differences in elevation are known accurately from the vertical deformation control survey. Furthermore, all distances are corrected for drift in the offset error of the EDM as determined by measurement with the calibration cap.

The corrected spheroid distances have been adjusted in two ways: 1) the ratio adjustment technique developed by Robertson (1975), and 2) a scale variation least squares adjustment developed at Virginia Polytechnic Institute and State University (Bryan, 1980). Both of these adjustment techniques account for the effect of changes in the index of refraction during the survey. Since the index of refraction affects the measured distance as a scale factor, an unknown scale factor expressed as a function of time is included in each adjustment method.

The ratio adjustment developed by Robertson at the Engineering Topographic Laboratories is currently used by the U. S. Army Corps of Engineers, Norfolk District to reduce all Gathright Dam trilateration data. The adjustment is a step-wise procedure in which the control network survey is adjusted by least squares, and then the intersection of corrected distances to movement monuments is determined by least squares. The control survey adjustment is a geometric condition adjustment of the triangle formed by stations 42, 43, and 45, followed by the adjustment of the braced quadrilateral formed by 41, 42, 45 and 46. In each adjustment, the condition is satisfied that the ratio of distances measured from a station does not change (Robertson, 1977 and Angus-Leppan, 1972). The control network is constrained in scale by an average length of several measurements on line 46 to 50.

After adjusted distances are obtained between control stations, ratios are determined between adjusted distances and measured distances. Repeated measurements on the control lines enable the scale ratio to be calculated for a given station at several times during the survey. Noncontrol lines to movement monuments are then corrected by ratios interpolated over time from the control lines. The corrected distances are used to compute the intersection coordinates at the movement monuments.

The results reported in this paper are taken from a new adjustment technique that accounts for scale variation but performs a simultaneous least squares adjustment of all measured data. The scale variation adjustment technique uses a variation-of-coordinates least squares computer program modified to include an unknown scale factor for each line. The idea is similar to an adjustment by Vincenty (1979), but here the scale factor is a continuous second-order polynomial function of time. The time of each observation is input to the program, and the algorithm determines the least squares best fit polynomial that models scale variation in the data. A different polynomial is used to model the scale variation on different days in a

survey. The program includes a distance constraint to fix a given line.

In the simultaneous scale variation adjustment, the observation of the distance from 49 to 50 was fixed at the same value used to scale the Corps of Engineers step-wise solution. For the five surveys reported in this paper, each made over three days of observing, the results of the two solutions were equivalent. However, the simultaneous solution has the following advantages:

1. A simultaneous adjustment of all data is performed,
2. Data is easily input to the program and a solution is obtained much faster,
3. An error analysis is immediately available using error ellipses to show the precision of the surveyed points.

Results. The results of five sequential surveys are shown in Figures 2 through 6 respectively. The positional error ellipses, relative to the fixed control, are shown at the 95% confidence level. The combined results of the five surveys is shown by the movement vectors in Figure 7. The movement vectors are plotted at the same scale as the error ellipses. The precisions obtained in the surveys are further demonstrated in Table 1 giving the standard deviation of unit weight from each survey. For the weighting scheme used in the program, the standard deviation of unit weight corresponds to a distance of approximately 600 feet.

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<u>Survey Date</u>	<u>St'd Deviation w/scale variation</u>	<u>St'd Deviation w/o scale</u>
July, 1978	0.0040 ft	0.0062 ft
June, 1979	0.0139	0.0154
Sept., 1979	0.0046	0.0049
Feb., 1980	0.0093	0.0149
March, 1981	0.0057	0.0068

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Table 1. Standard Deviation of Unit Weight for the Distance Residuals

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Table 1 shows poor results for the June, 1979 survey relative to the other surveys. Since the standard deviation scales the error ellipses, the ellipses in Figure 3 are correspondingly large. Examination of the individual distance residuals leads to the conclusion that there may be a blunder in the measurement of line 46 to 45; however all data is included in the results reported in this paper.

## GATHRIGHT VERTICAL SURVEYS

The same monuments used to monitor horizontal movement of the dam structure were used to monitor vertical movement. The procedures and results of the vertical survey are briefly reported herein.

Procedures. The original vertical monitoring plan for surface movement points was to employ vertical angles. However, considering the state of the art for using theodolites to measure precise vertical angles and the problems associated with refraction, it was decided to employ standard leveling techniques to monitor vertical movements. Standard first-order precision levels are double run to all surface movement points in accordance with the standards of accuracy and specifications as published by the U. S. Department of Commerce, NOAA/NOS, February, 1974.

Equipment. The first level instrument used was a Wild N-3 precision level with double scale invar rods. This was very accurate but also very time consuming, and it was a traditional spirit level with split bubble and plane parallel plate micrometer. The instrument now in use is a Wild NA2 automatic level with detachable plane parallel plate micrometer. Double scale invar rods graduated to 1 cm with attached rod stands have also replaced the older type rods. This system is capable of reading to 0.1 mm with estimation to 0.05 mm.

Adjustment. All levels are double run, and the mean of the front and back runs are computed in addition to the mean of the double scale rod readings. More complicated adjustments of the level network are not possible at this time. This is due to the fact that there is only one project bench mark.

Other marks have been set as back-up marks; however, long term and seasonal settlements and uplifts indicated by the leveling prevent assuming other marks are stable as compared to the project bench mark. It should be noted that bench marks were set on the right abutment to monitor the upstream and downstream faces of the dam and along the stilling basin road to monitor the stilling basin. All other movement monuments are surveyed from the project bench mark.

Results. The results of the vertical surveys are shown in Figure 8. The settlement curves for the monuments on the top of the dam only are shown. The curves follow the sequence of surveys from July, 1978 to February, 1980.

Monument 29 has shown the largest displacement with a total settlement of 0.55 ft (167.6 mm). The leveling surveys have continually yielded results accurate to  $\pm 0.001$  ft (0.3 mm) with a confidence level of 95% relative to the particular bench mark used for monitoring.



## LOGAN-MARTIN DAM PROJECT

The Logan-Martin Dam is located near Birmingham, Alabama. The dam was in place and operational prior to the four surveys that are discussed in this paper. The surveys were performed May and November 1980 and May and August 1981.

Procedures and Equipment. The Logan-Martin Dam field surveys include both angle and distance observations. The distance observations are shown in Figure 9, and the angle observations are depicted by the lines of sight shown in Figure 10. All observations are made from control monuments numbered 31 through 37 in the figures. Dam movement monuments numbered 1 through 18, 30, 38, and 39 are located by distance and angle intersections only. All control and movement monuments are concrete pillars with forced centering for instrument and target setups.

Angle observations are made with a Wild T3 theodolite. Each angle is measured using 16 positions with a 4-second rejection limit. Distance observations are made with a Hewlett-Packard 3808 EDM. The error specification for the HP 3808 is given as  $\pm .016 \text{ ft} \pm 1 \text{ ppm}$  by the manufacturer. No special calibration cap is used as in the Gathright Project. Slope distances are reduced to horizontal using the difference in elevation between monuments established by precise leveling methods.

Data Adjustments and Results. Since both angles and distances are available, the Logan-Martin Project can be used to compare the techniques of triangulation and trilateration as well as a combined survey of all angle and distance observations. Each of the four survey data sets was adjusted by least squares in three ways: 1) combined observations, 2) angles only, 3) distances only. In cases 1 and 3, the distance observations were adjusted for scale variation using a continuous scale model determined by the adjustment program as described previously. The results of the surveys are summarized by the standard deviation of unit weight in Table 2. For the weighing scheme used in the program, the standard deviation of unit weight corresponds to a distance of approximately 2600 feet.

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<u>Survey Date</u>	<u>Combined Data</u>	<u>Angles Only</u>	<u>Distances Only</u>
May, 1980	.0097 ft	.0053 ft	.0092 ft
Nov., 1980	.0105	.0151	.0064
May, 1981	.0101	.0126	.0064
Aug., 1981	.0114	.0082	.0104

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Table 2. Standard Deviation of Unit Weight for Three Survey Methods.

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The analysis of Table 2, and an analysis of adjusted station coordinate differences between the three methods indicates no significant difference in station position if

trilateration, triangulation, or combined observation survey methods are used.

Each survey is adjusted holding fixed coordinates on stations 31 and 34. The precisions of locating the free monuments relative to the fixed monuments are shown by the station error ellipses on Figures 11, 12, and 13. These figures show the distance only, angle only, and combined observation adjustment method respectively for the August 1981 survey, but they are typical of all the surveys.

It is interesting to note that the Logan-Martin Project distance observations have also been corrected by hand using Robertson's scale variation method. No significant difference in results has been found between the hand corrections and the least squares simultaneous determination of scale used in this paper.

The final movement vectors plotted at error ellipse scale are shown in Figure 14.

#### CONCLUSION

The survey methods used to monitor horizontal and vertical displacements on the Gathright Dam are capable of determining horizontal displacements to within  $\pm 0.030$  ft ( $\pm 9$  mm) and vertical displacements to within  $\pm 0.001$  ft ( $\pm 0.3$  mm) at a 95% confidence level. Although no special leveling techniques were employed, the horizontal accuracy obtained does require monitoring the offset error in the EDM and inclusion of an atmospheric scale variation parameter in the adjustment technique. Of course, both horizontal and vertical accuracies depend upon optimum survey system design and proper use of instruments.

The Logan-Martin Dam Project results also support the conclusion that proper survey design, monument design, and proper use of instruments is essential to obtaining accurate movement measurements. The data suggest that adequate accuracies can be obtained using trilateration methods, and time consuming angle observations can be eliminated. The results of the horizontal analysis indicate that horizontal displacements can be determined to an accuracy approaching the Gathright Project.

#### ACKNOWLEDGEMENTS

The authors wish to express their thanks to the U. S. Army Corps of Engineers and the Alabama Power Company for their cooperation in making the data available. We must also recognize the individual efforts of Charles Babcock and Anthony Moraco at VPI and Stephen Deloach at the Norfolk District Office in helping to prepare the Gathright data sets for analysis; and to Roy Teal and Dennis Boston of the Alabama Power Company for their help to obtain the Logan-Martin data sets.

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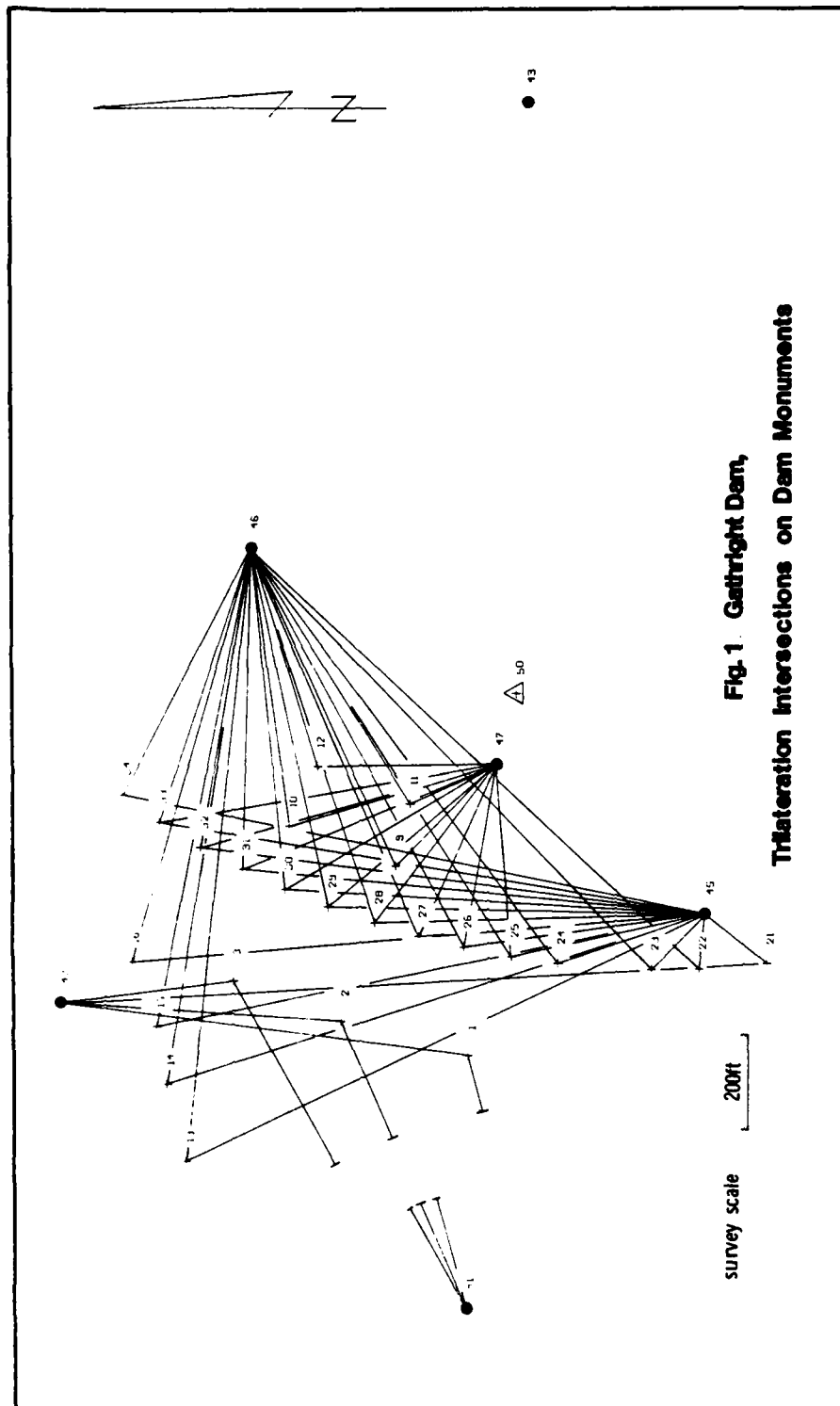
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**Fig. 1. Gathright Dam,  
Trilateration Intersections on Dam Monuments**

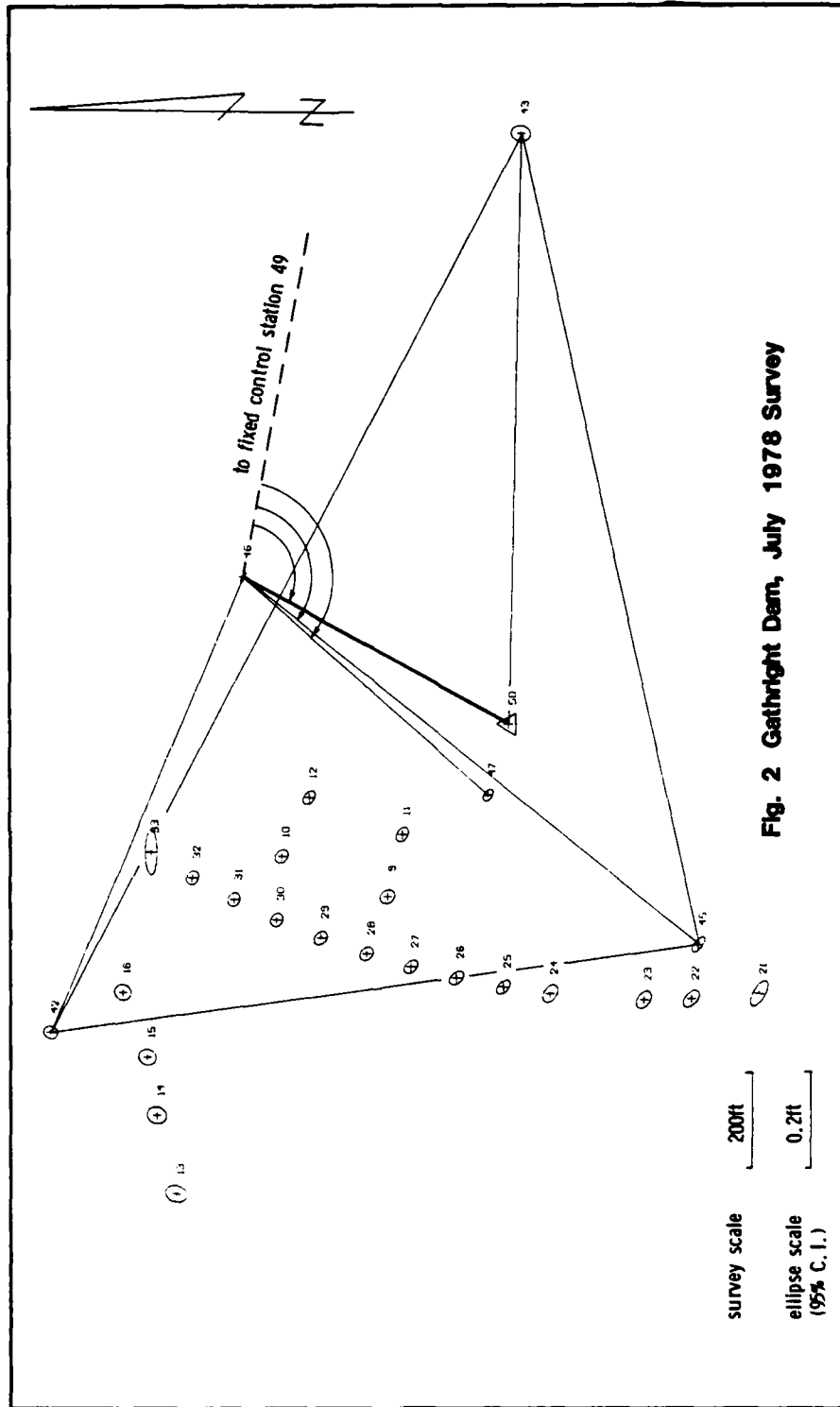
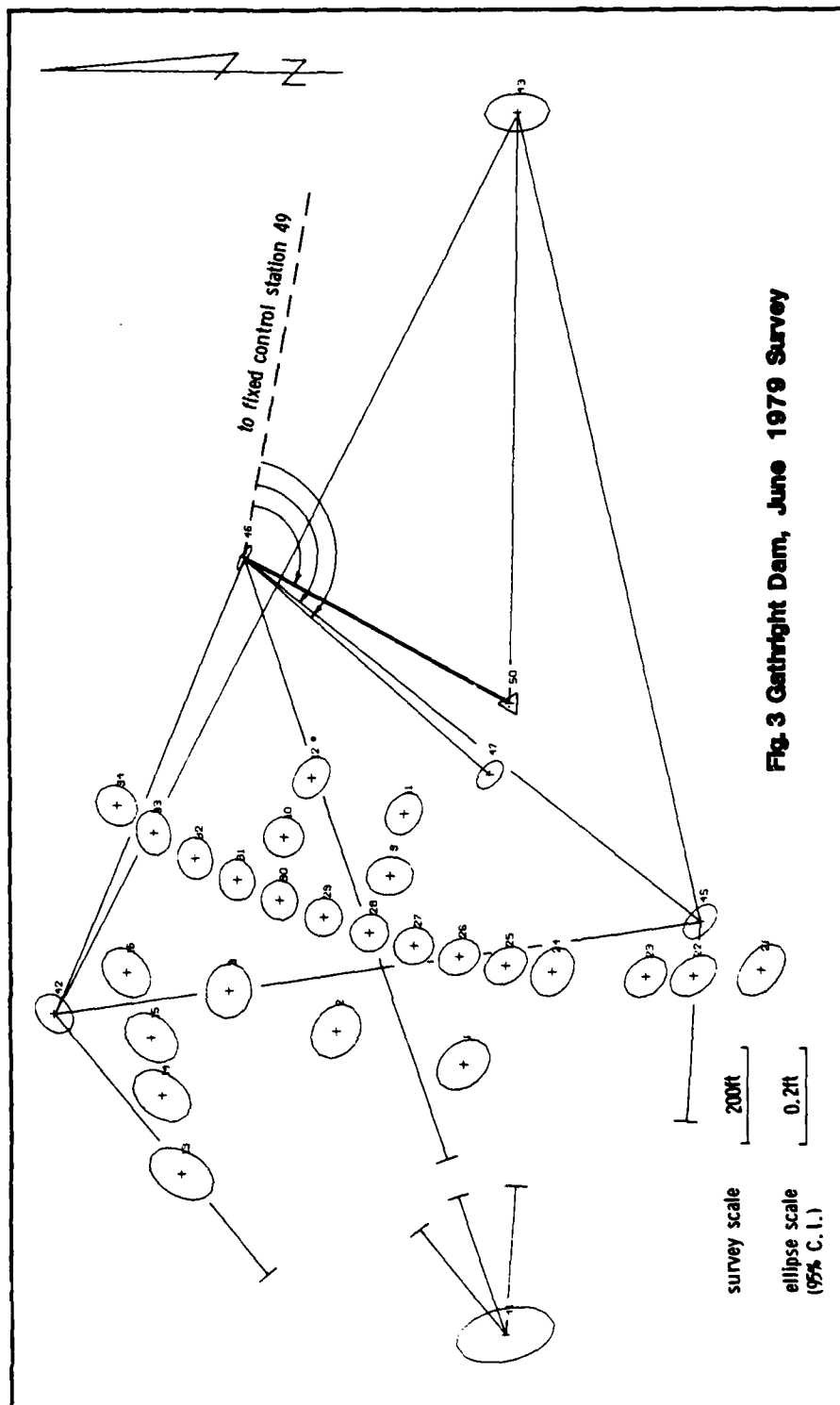


Fig. 2 Gathright Dam, July 1978 Survey



**Fig. 3 Gatright Dam, June 1979 Survey**

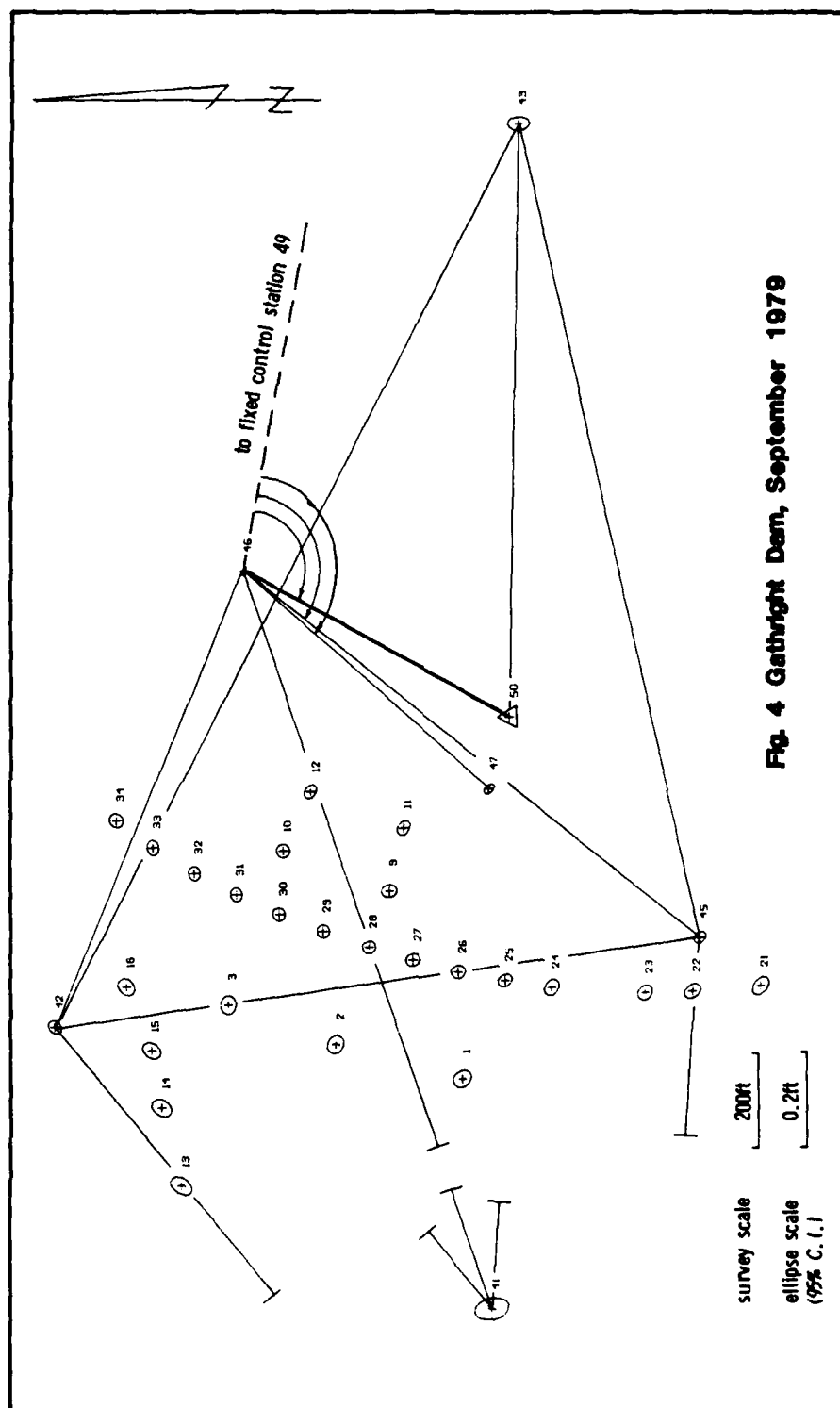


Fig. 4 Gathright Dam, September 1979

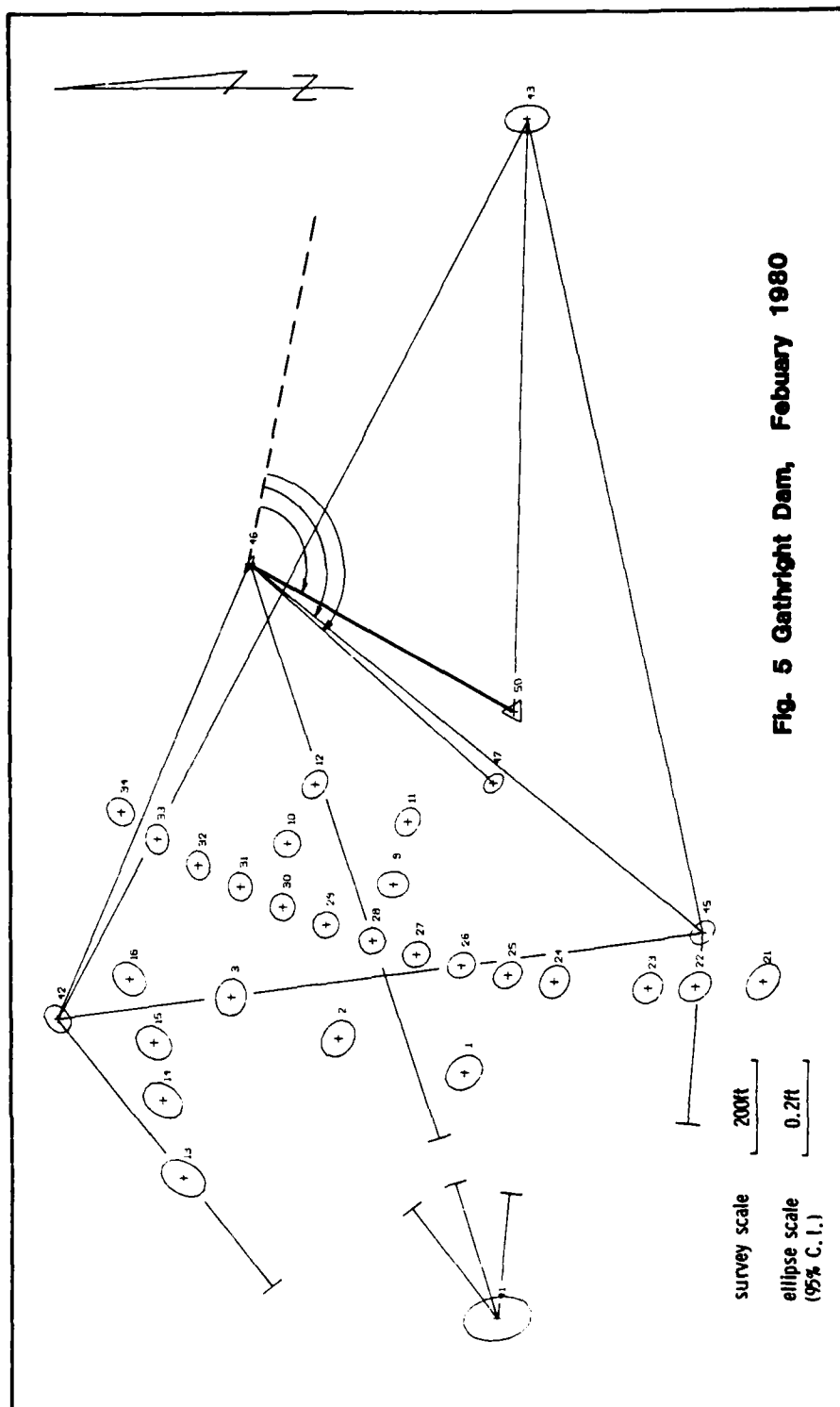


Fig. 5 Gathright Dam, February 1980



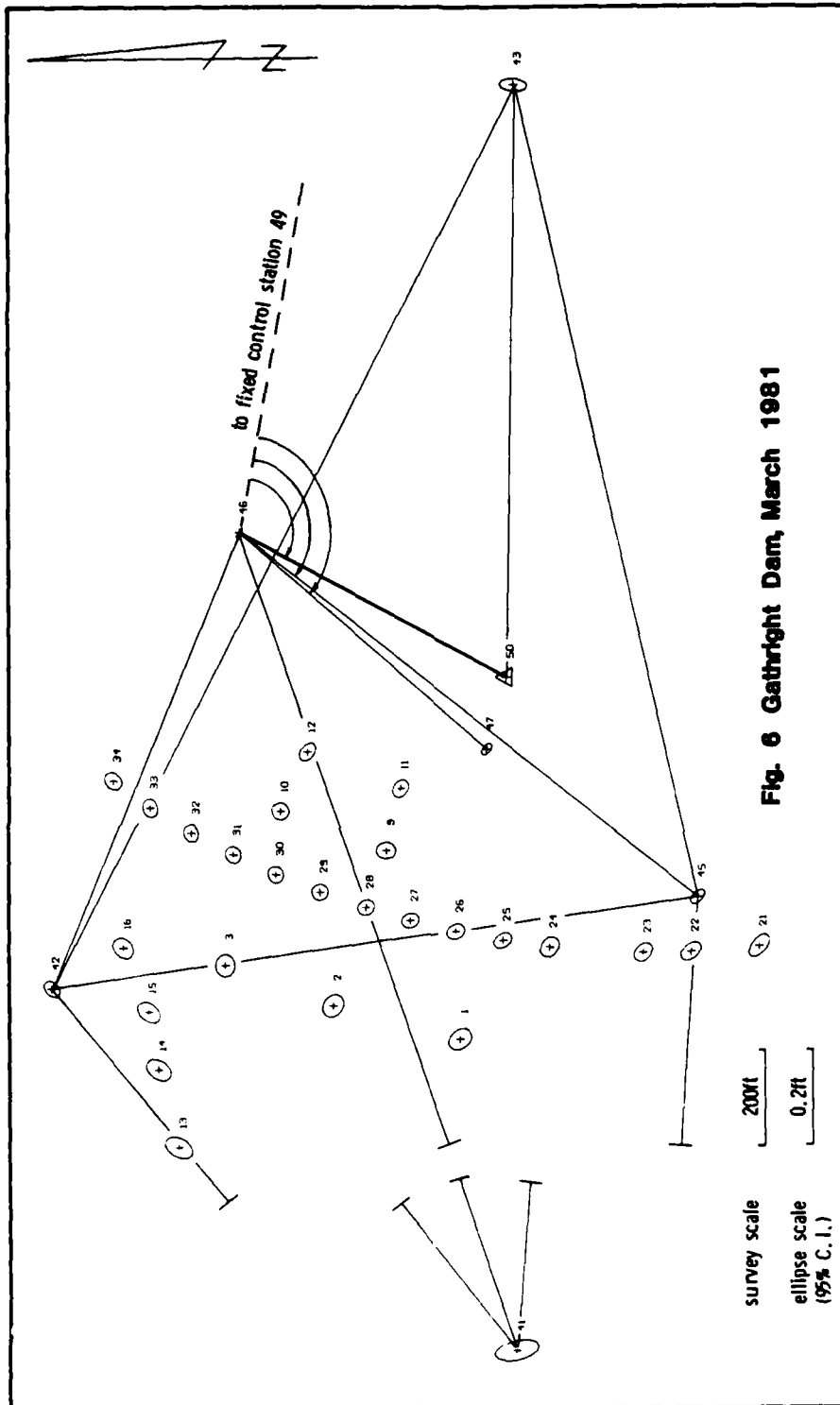
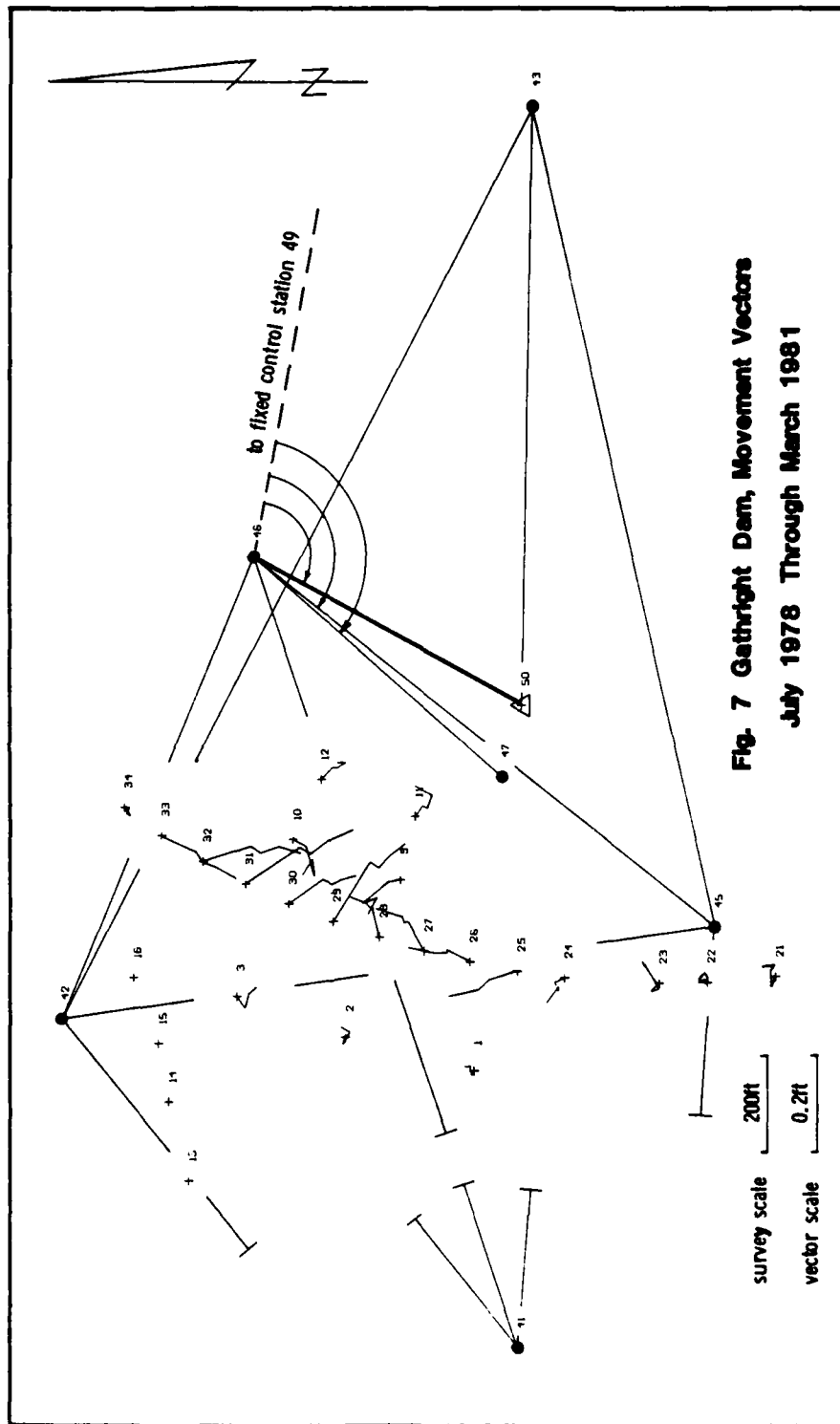


Fig. 6 Gathright Dam, March 1981



**Fig. 7 Gathright Dam, Movement Vectors  
July 1978 Through March 1981**

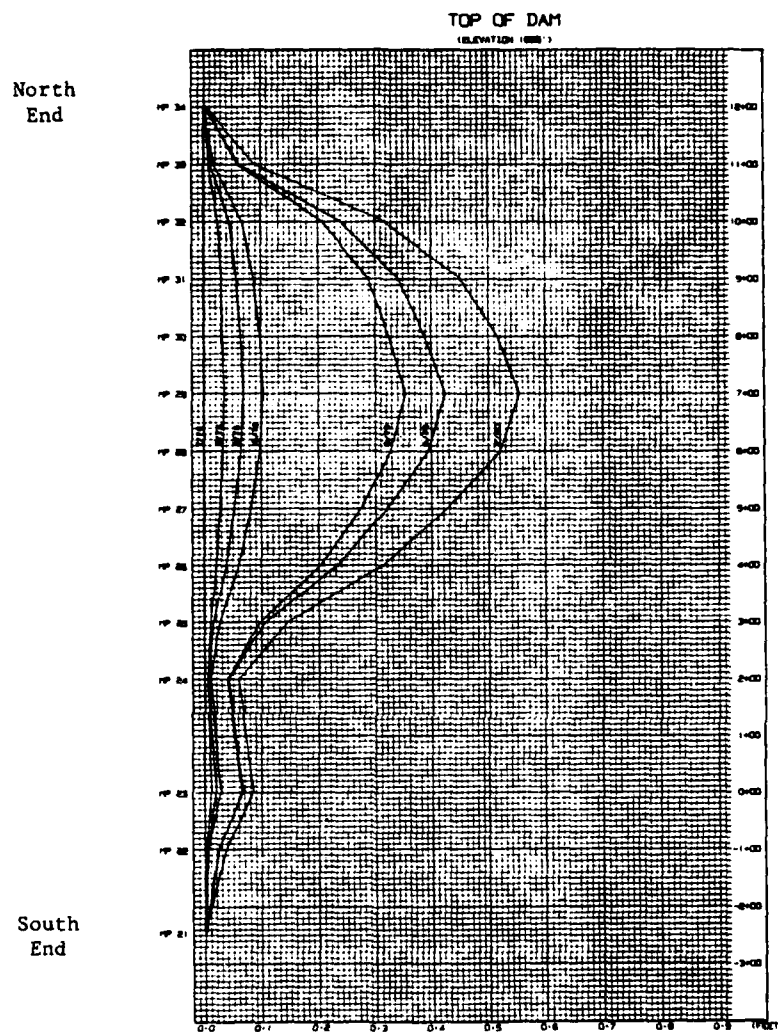


Figure 8. Vertical Displacement Along Top of Dam.

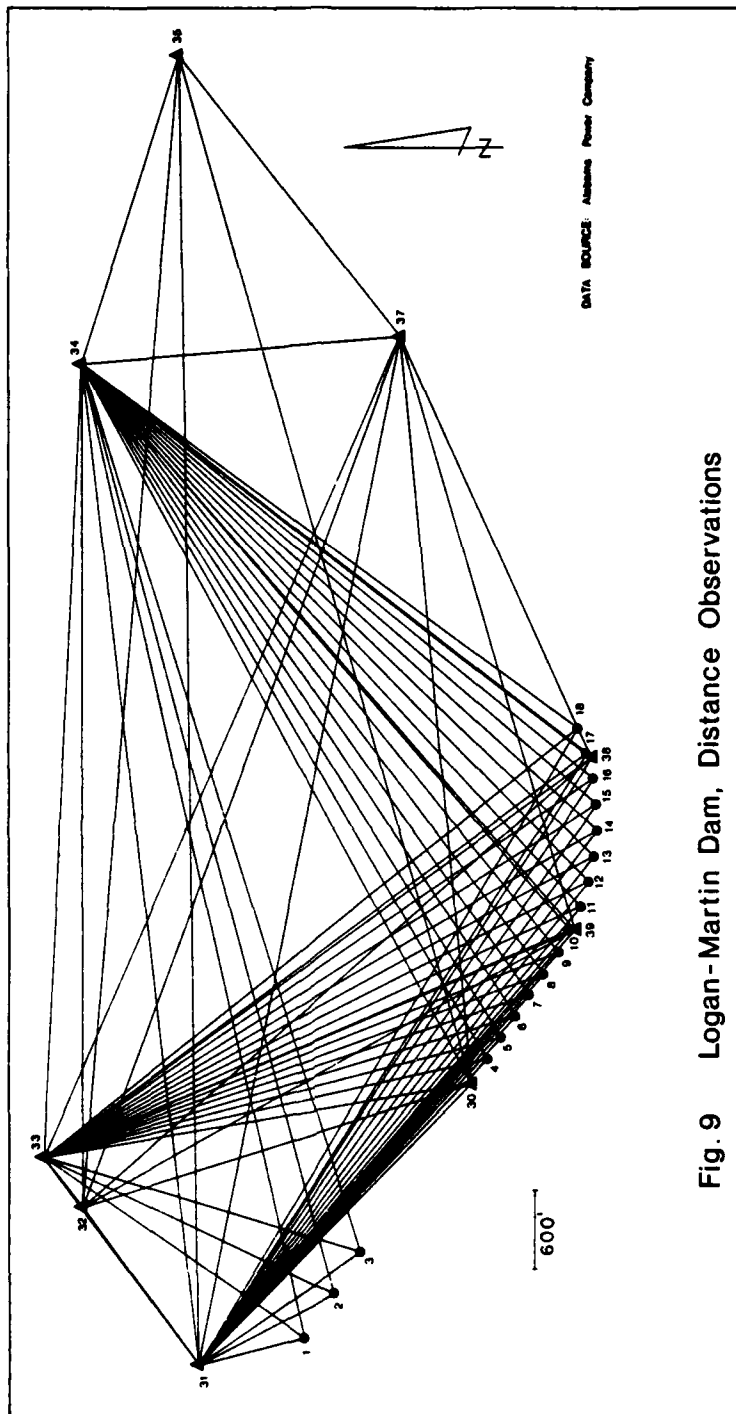


Fig. 9 Logan-Martin Dam, Distance Observations

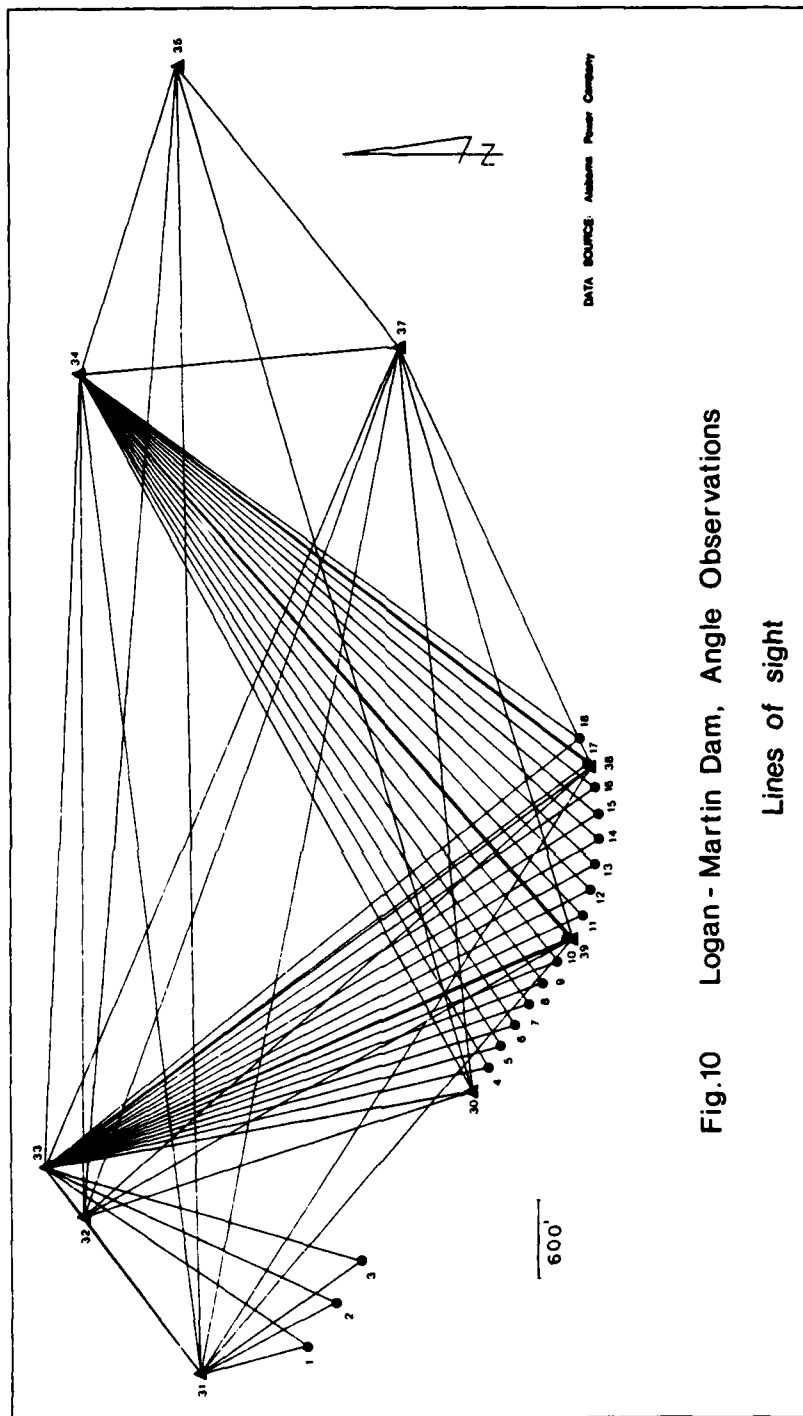
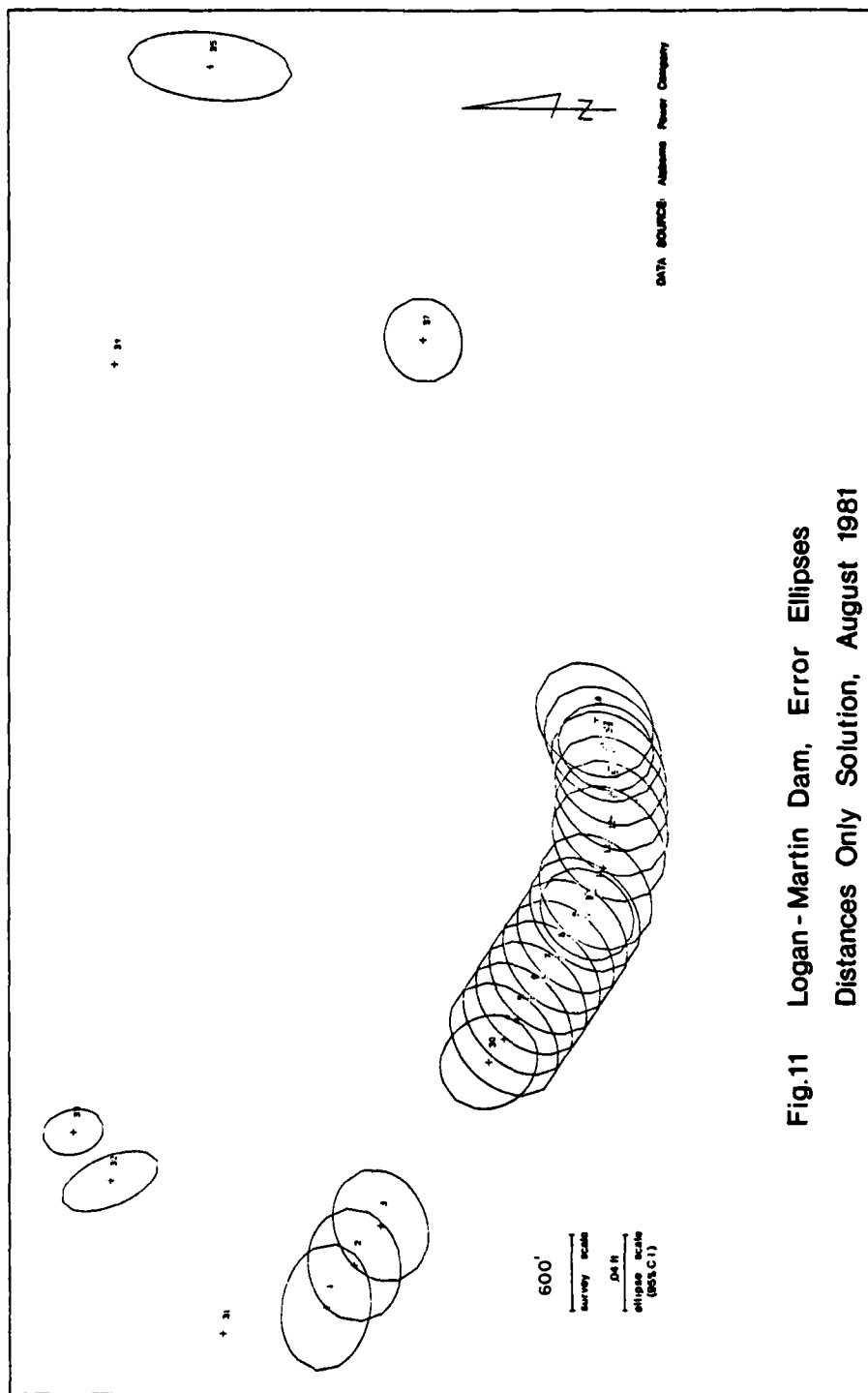


Fig.10 Logan - Martin Dam, Angle Observations  
Lines of sight



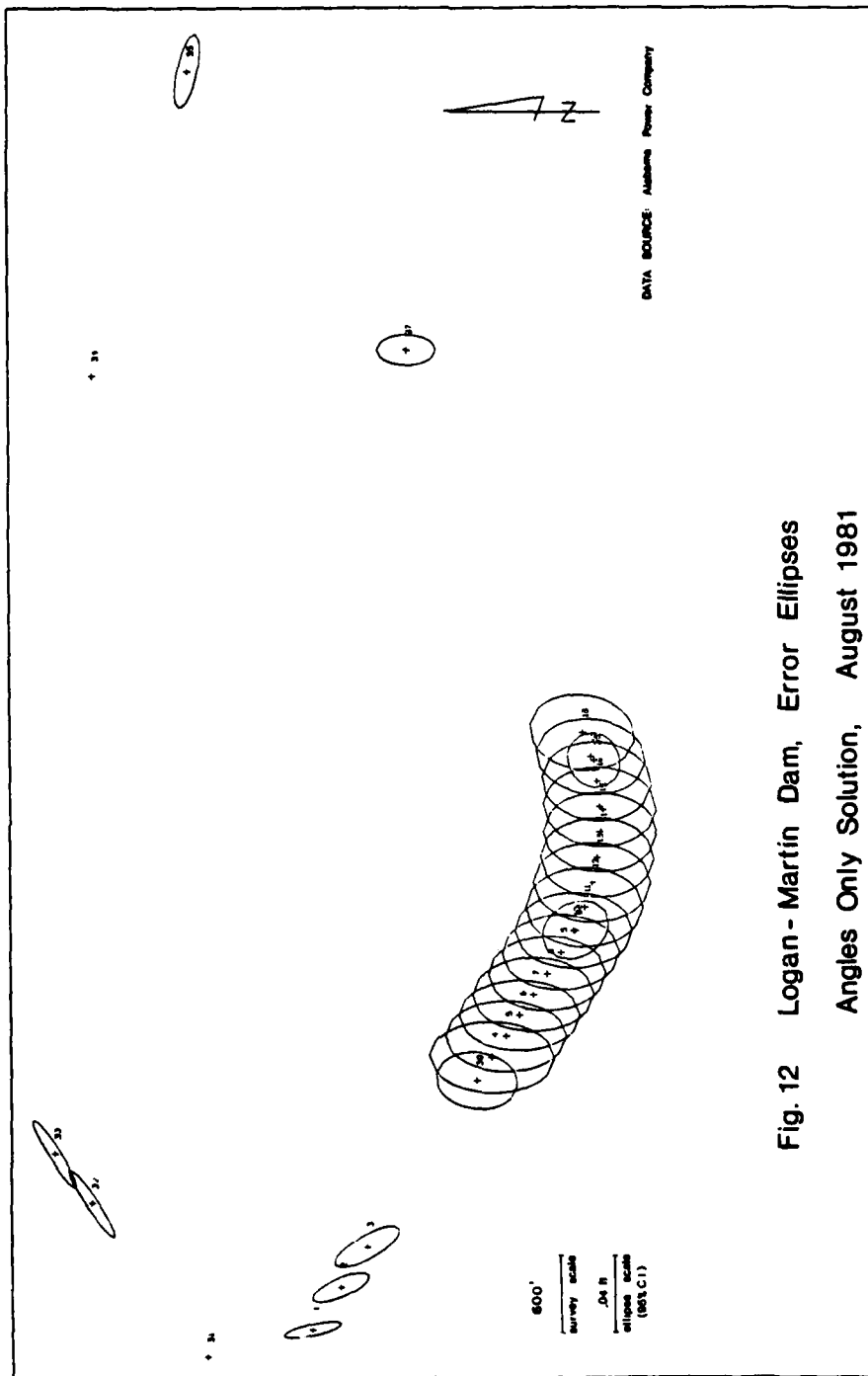
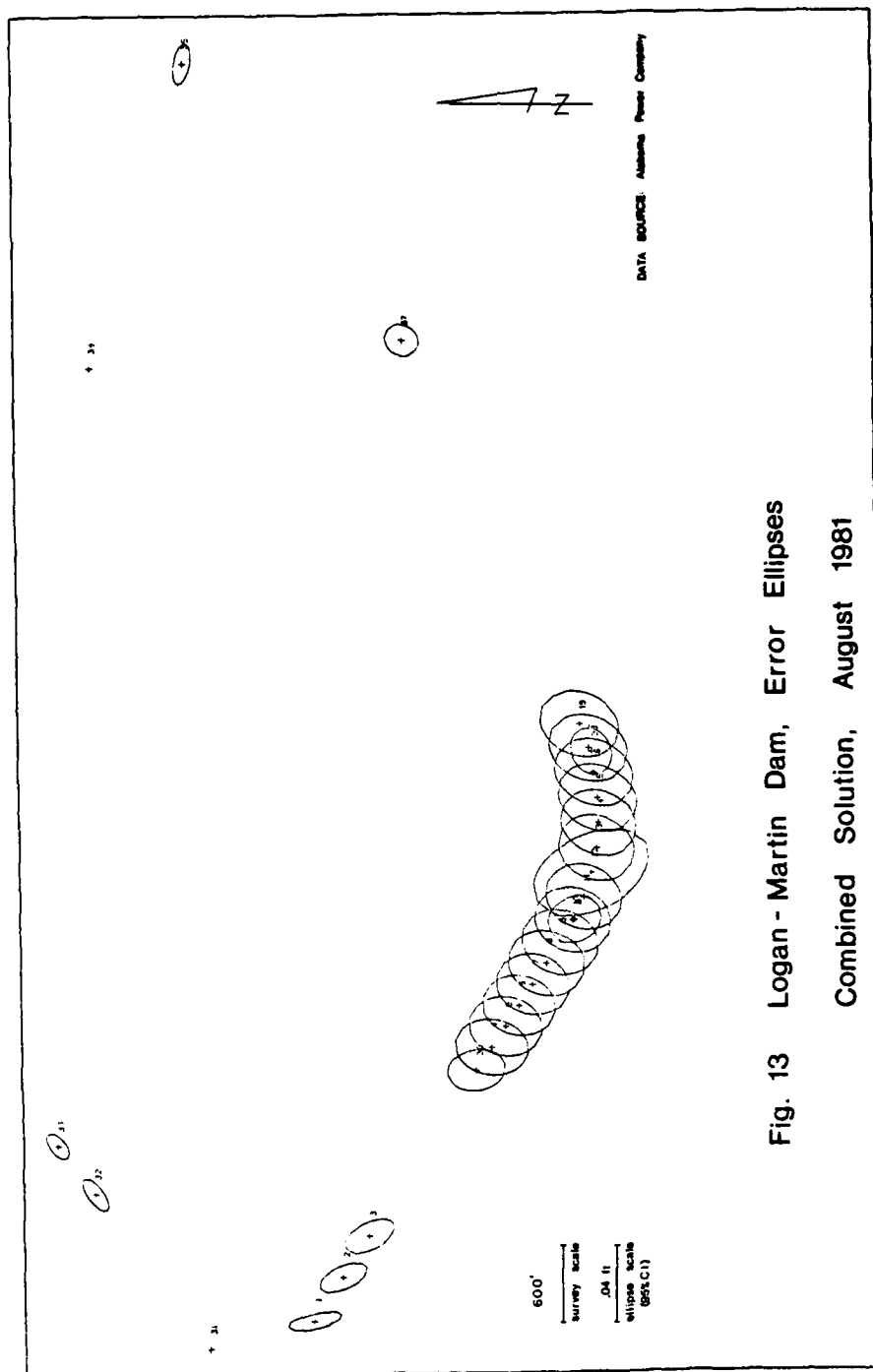


Fig. 12 Logan-Martin Dam, Error Ellipses  
Angles Only Solution, August 1981





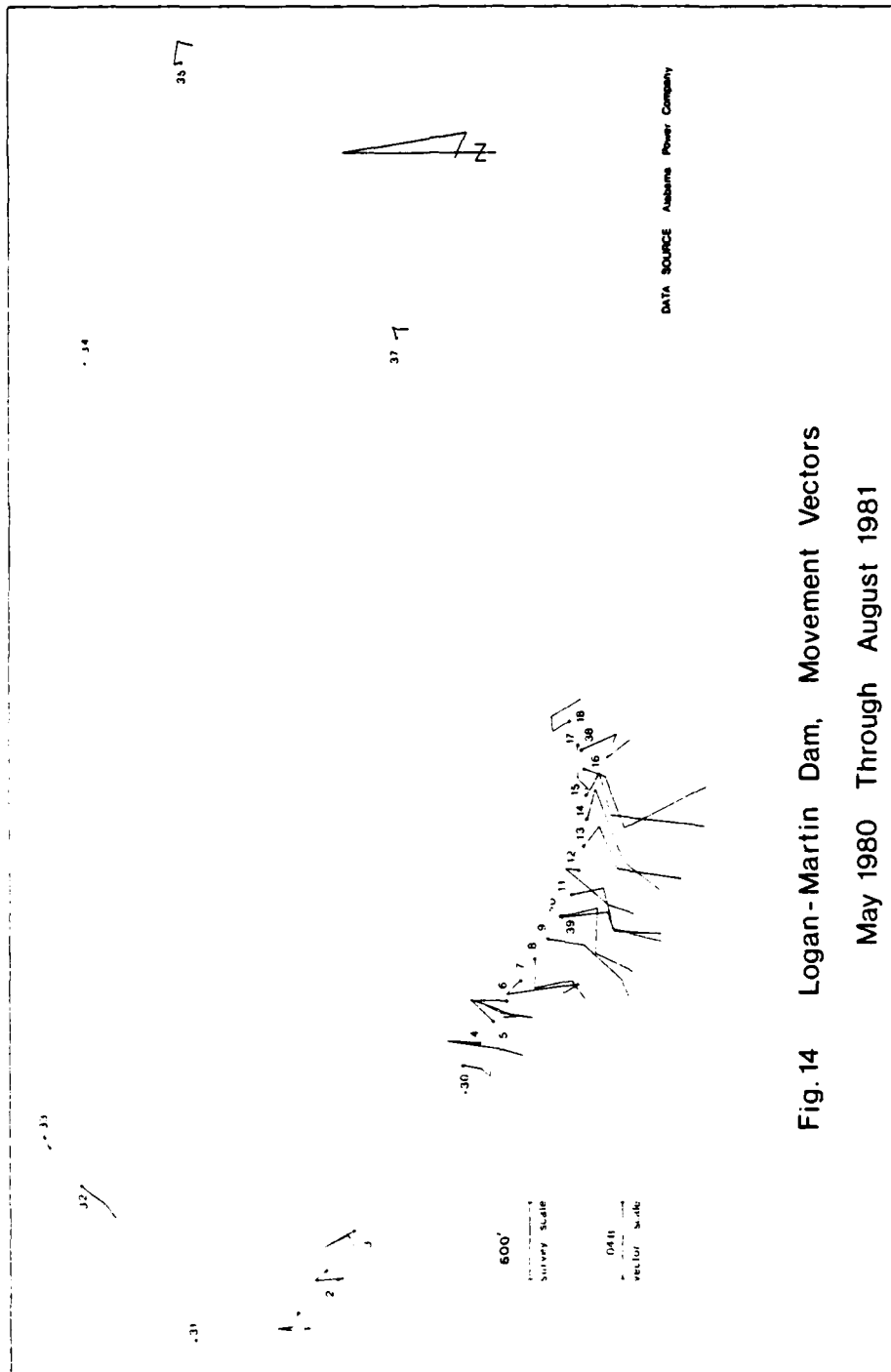


Fig. 14 Logan-Martin Dam, Movement Vectors  
May 1980 Through August 1981

DATA SOURCE Alabama Power Company

## MEASURING TILT WITH AN AUTOMATIC LEVEL

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### BIOGRAPHICAL SKETCH

Kenneth Robertson is a research physicist with the Engineer Topographic Laboratories where he is concerned with the development of advanced surveying instruments and techniques. While at ETL, he has developed a falling body device to measure absolute gravity, a laser alignment instrument for use on dams, a non-contact optical method of measuring velocity, a means of measuring angles without circles or encoders, and the present technique of measuring tilt. Mr. Robertson also developed the ratio techniques used in dam monitoring with distance measuring instruments. He is a 1951 graduate of Indiana University.

### ABSTRACT

The long-term or short-term tilt of structures such as locks or dams may be measured with an automatic level which has been temporarily modified for the purpose. The modifications consist of the addition of an autocollimating eyepiece and an optical vernier. A calibration mirror is also required for the measurement of long-term tilt. Accuracies of 1 to 5 seconds of tilt may be obtained.

### INTRODUCTION

Large structures such as locks and dams need to be continuously evaluated to insure their structural safety and stability. Such evaluations should be supported by programs of instrumentation that will provide a means of detecting structural distress or abnormal operating conditions. One vital piece of information is the degree to which a structure tilts or bends under load.

Normally these measurements are made through the installation of a plumb line or an inverted plumb line or an optical plummet. Tilt is inferred from the displacement of the plumb bob and the length of the plumb line. Measurements of displacement at intermediate points along the plumb line give information regarding bending of the structure. Plumb lines, however, suffer from some serious drawbacks. They are expensive. Installation in a single monolith may cost as much as \$50,000, and it must be installed during construction of the dam. Because of this only one or two monoliths in a dam are usually equipped. In

addition, the plumb lines lack sensitivity near their points of suspension, necessitating the use of an inverted plumb line. To monitor bending in a monolith, both types may be required. Finally, plumb lines lack sensitivity on shorter structures. A deflection of 10 seconds in a dam 20 meters high gives a deflection of only 0.1 millimeters.

The purpose of this paper is to describe an instrument which measures tilt directly. The instrument consists of a Zeiss Ni 2 Automatic Level, an autocollimating eyepiece, an optical vernier, and a calibration mirror. Long-term measurements of tilt are made of permanently mounted mirrors. These are attached to each vertical surface where a measurement of tilt is required. As the vertical surface tilts, the mirror follows the movement and the instrument is designed to detect these small deflections. For short-term measurements, such as those encountered during the fill, empty cycle in a lock, a tripod mounted mirror may be used.

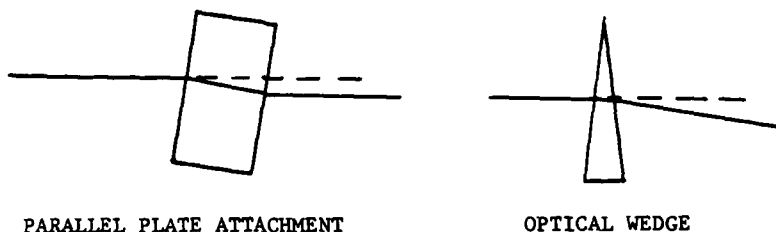
The instrument accuracy for measurements is about one second of arc over a range of plus or minus 7.5 minutes of arc. Using the qualities of the pendulum compensator in the level and a calibration mirror, all measurements are referred directly to the local gravity vector. Because of the calibration, the instrument is virtually free of the effects of drift in the compensator. While not being used to measure tilt, the automatic level may be returned to its normal function.

#### THE LEVEL AND AUTOCOLLIMATING EYEPIECE

The autocollimator is a device which is widely used in optical tooling for measuring small angles. It consists of a small telescope which has been focused at infinity. At the focal plane of the eyepiece of this telescope, a crosshair reticle is placed. A small light source is then added to illuminate the reticle and the image of the reticle is projected along a collimated beam from the telescope. If the beam strikes a mirror which has been placed in position perpendicular to the axis of the telescope, the image of the crosshair will be reflected back into the telescope and will come to a focus at the same spot as the original crosshair. If the mirror is then tilted slightly, an observer looking through the autocollimating eyepiece would see the image of the crosshair slightly displaced from the original crosshair. The amount of displacement is a sensitive measure of the angular tilt of the mirror. Instruments of this nature have been in use in the laboratory and in the optical tooling industry for many years.

An autocollimating eyepiece for the Zeiss Ni 2 level will convert the level to an autocollimator. The

eyepiece contains an additional reticle which enables the user to measure the displacement of the crosshair and thus the angle of tilt of the mirror. The reticle is graduated in 10 second intervals and estimations may be made to two or three seconds of arc. For finer readings, an optical vernier is added. The vernier consists of a thin wedge of glass which bends the line of sight in the direction opposite the point of the wedge. This should not be confused with the parallel plate attachment for the level which is used as a vernier when a normal leveling course is being run. The parallel plate attachment, as the name implies, uses a thick plate of glass with parallel sides. The plate is tilted in the optical path to displace the line of sight, but without bending it through an angle. The figure shows the difference between the two attachments.



If the optical wedge is rotated, the line of sight may be deviated up, down, right, or left. An observer viewing the image of the crosshair reflected from a mirror and passing through the optical wedge would see the crosshair move in a circle as the wedge was rotated. Left, right motions of the crosshair may be disregarded and only the up, down motions used. The wedge may be calibrated so that deviation of the line of sight is equated to rotation of the wedge. In use, the wedge is rotated until the crosshair image is brought into coincidence with one of the reticle graduations. The rotation of the wedge needed to accomplish this is then an accurate measure of the difference in seconds between the image and the reticle line. The deflection of the crosshair image and the tilt of the mirror causing the deflection may now be read to approximately 0.5 seconds of arc using the optical wedge.

Each time the instrument is used to measure the tilt of a mirror the line of sight of the instrument must lie along the same plane. Because an automatic level is the telescope of the autocollimator, the line of sight lies in the horizontal plane and all measurements are referred to the horizontal.

Although the compensator in an automatic level will maintain a reproducible line of sight over an extended period, this line may not be perfectly horizontal. This is the reason that foresights and backsights need

to be balanced in high order leveling. For the purpose of measuring tilt it is necessary to determine the departure of the line of sight from the horizontal because the compensator may change over long periods or be disturbed by rough handling. In addition, the autocollimating reticle may not be placed in exactly the same position each time, further disturbing the horizontal reference of the readings. Thus it is necessary to have a simple means of calibration for the instrument which may be used immediately before and after a day's set of readings.

#### THE CALIBRATION MIRROR

This is provided by means of a special mirror. If it were possible to make this mirror perfectly vertical, a reading of the mirror by the instrument should show zero tilt. If it does not, it is because of the errors in the compensator and in the positioning of the autocollimator reticle. Because the mirror is vertical, the total error may be read directly from the reticle and optical vernier, and the results applied as a correction to subsequent readings.

The calibration mirror is one which is ground and polished to have faces which are parallel to within 0.5 seconds of arc. This mirror is mounted to a tribach in an approximately vertical position and a reading of tilt is made of one face with the instrument. Without moving the mirror the instrument is then used to make a reading of the other face. If the mirror were perfectly vertical both readings would be the same even if the instrument line of sight were not horizontal, and the difference of the readings from zero would be the error in the instrument. If the mirror were not vertical, the two readings would not agree, but the mean of the two would be the error of the instrument. This calibration takes less than 20 minutes to perform and should be done at the beginning and end of each day's readings to check for drift. Typically the difference will be less than 2 seconds and the mean of the two sets may be used to correct the intermediate readings of the mirrors monitoring tilt of the structure.

A set of measurements at a dam would then consist of an initial calibration with the calibration mirror, a reading of each of the mirrors mounted in the structure, and then a final set of calibration readings. Each calibration takes about 20 minutes and the reading of each mirror in the structure takes about 5 minutes. Accuracy of the reading of the instrument is about 2 seconds of arc.

#### STRUCTURE MIRRORS

An essential part of the tilt monitoring system is the

structure mirror. This must perform several functions. The mirror must be mounted in such a manner that it accurately follows the tilt of the structure, the mount must not distort the mirror so that an unclear image is seen in the autocollimator, and the mount must provide a means of setting the mirror to an almost vertical initial position so that the image of the crosshair will be near the center of the range of the instrument.

Providing for these requirements has proved to be the most difficult part of the work. Each mirror was first affixed to an aluminum plate using a slow curing epoxy cement. Most of the mirrors treated in this way gave good results, but a few were strained enough by the mounting process to return fuzzy images in the autocollimator.

Next, a backing plate for each mirror was attached to the wall of a gallery using a structural epoxy cement and the epoxy was allowed to cure for two weeks. Finally each plate with its mirror was mounted to a backing plate using a three point adjustable suspension under spring tension. The suspension was then adjusted using the autocollimator to bring the mirror into an approximately vertical position. An additional two weeks was allowed for the strain in the suspension to be relieved and the first set of readings was taken. Each mirror assembly was provided with a protective cover.

## RESULTS

Two types of tests have been performed with the tilt measuring system. The first test was in the gallery of Philpott Dam near Roanoke, VA. Here, six mirrors were mounted in a gallery, four on the downstream wall and two on the upstream wall. All were in the same monolith so that the tilt in each mirror should be the same, and the characteristics of the mirror mounts could be tested. Surprisingly, the mirror mounts required three months to stabilize, due perhaps to the cool temperatures encountered in the gallery.

After the mounts had stabilized, readings showed a steady downstream tilt for the next three months with a total tilt of about 30 seconds of arc. It is believed that the measurements represent the true tilt or bending of the structure with an accuracy of  $\pm 5$  arc seconds. This accuracy figure is derived from the agreement of the four mirrors on the downstream wall, and from the two mirrors on the upstream wall which give values of the same magnitude but of different direction. If the downstream mirrors are tilting with their upper edges away from the instrument, then the upstream mirrors should show their upper edges tilting towards the instrument.

A second type of test was performed at Holt Lock and Dam in the Mobile District. Here it was desired to measure the tilt of a lock wall during the fill, empty cycle. The instrument and the calibration mirror were set up on tripods so that tilt of the lock wall would cause the calibration mirror to tilt in a like manner. Calibration was not required because relative values of tilt were to be measured over a short period of time without disturbing the instrument or mirror. A time of day near evening was picked to reduce the effect of temperature changes on the calibration mirror and tripod. In addition, an umbrella was used to shade the mirror. A tilt of 12 seconds of arc was measured between full and empty conditions of the lock. After emptying of the lock, less than one second of change was seen over the next several hours.

### CONCLUSIONS

An instrument has been developed to monitor tilt in large structures. The instrument consists of an automatic level, an autocollimating eyepiece, an optical vernier, and a calibration mirror. Also required is a wall mounted mirror which will follow the tilt of the structure. Tests of the instrument reveal that measurements of tilt may be made with an accuracy approaching one second of arc. Work is continuing to improve the stability of mirror mounts to be used in permanent installations, but measurements with an accuracy of 5 arc seconds are presently possible. Cost of the instrument is about \$4000 plus the cost of the Zeiss Ni 2 Automatic Level. In addition each monolith to be monitored should have two mirrors installed, one on the upstream and one on the downstream wall of a gallery. The cost would be approximately \$300 per monolith. A complete report on this work is in preparation.

SESSION XII: TOPOGRAPHIC SURVEYING - MISCELLANEOUS TOPICS



Jimmy Reaves  
Mobile District  
Chairman

*Speakers*



Harry Coupland  
Marshall Macklin  
Monaghan Limited



Cleveland Powell  
Jacksonville District



Doug Wilcox  
Bureau of  
Land Management



SESSION XII

TOPOGRAPHIC SURVEYING - MISCELLANEOUS TOPICS

Summary

The papers of Messrs. Coupland, Powell, and Wilcox give us an overview of where we have been, where we are, and where we are going.

The surveying and mapping segment of the Corps of Engineers is emerging upon the beginning of a new era--that of Digital Surveying. This will affect all aspects: Hydrographic, Topographic, Land Surveying, and Photogrammetric Mapping.

TOWARDS AN INTEGRATED FIELD DATA  
COLLECTION METHOD

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BIOGRAPHICAL SKETCH

Harry G. Coupland is an Ontario Land Surveyor engaged in the development of new technology in the Surveying and Mapping Division of Marshall Macklin Monaghan; a national firm of consulting engineers, surveyors and planners, where he is Co-ordinator of the Applications Unit. His professional experience, since 1954, has included cadastral and control surveys, private practice, teaching and more recently, computer science applications in an integrated survey environment. He is a member of the Association of Ontario Land Surveyors and provincial councilor for the Canadian Institute of Surveying.

ABSTRACT

Marshall Macklin Monaghan has developed an integrated system to gather topographic and other data in the field as swiftly and automatically as field procedures permit. It allows for input from various measurement methods for lower order surveys such as stadia to the more sophisticated and highly automated total stations. A particular feature is the storage and transmittal of data from an electronic field book developed specifically for this application. Output may be any number of special listings or plots that are created with a minimum of manual intervention.

The system is fully operational and has been proven over the past two years on numerous types of surveys. All necessary equipment is readily available and the programs have been released for use through time sharing computer facilities.

The paper describes the system and illustrates, through examples and photographs, the numerous survey applications. Particular emphasis will be placed on pipeline surveys, utility mapping, volumetric and topographic surveys of extensive areas.

INTRODUCTION

In 1979 our firm was asked to provide topographic maps of a road in a mid-east country for design purposes. The road passed through very rough desert country and very close to the border of a hostile country. The only sensible way to survey the road was by photogrammetric mapping techniques, but since the aircraft had to fly over the enemy country in order to complete some of the flight lines of photography, it was thought best to complete that portion of the contract by ground methods. This particular assignment brought about the birth of our integrated survey system.

## THE TOPOS SYSTEM

For many years we had used a version of COGO to reduce field notes to co-ordinates and plot whatever was needed. Our COGO package did not allow for alphanumeric labelling of points, nor did it allow for the computation and presentation of the vertical dimension, and could not easily be adapted for the project at hand. This prompted us to write a new program that would centre around efficient field procedure rather than around geometry and which would permit and encourage manipulation of the surveyed points by their descriptions as well as by the usual point number.

FORTRAN was chosen as the language and because we did not want any limitations on the number of points that could be handled at any one time, we decided to use a disk file as the dynamic and static storage device. The program was called TOPOS for the lack of a better name. It has now grown to include some 120 commands and variations, and has become known as a system rather than a program.

TOPOS was designed before the advent of the current "Total Station" theodolites, but because it is based on the same simple surveying method, it can be used to reduce the data from any surveying device with a minimum of change.

### Field Recording Methods

Each branch of surveying has, over the years, developed its own procedures. Methods for the same type of survey vary between organizations. Particular party chiefs have their own style and technique. In North America, where individual efforts and accomplishments are held in high esteem, this approach is commendable.

Unfortunately, this individualized, every-man-for-himself style of surveying created many problems, some of which showed up in the drafting room, some at the time of computer coding and others later in the field when a project was being retraced. In today's society, where efficiency is the prime objective, where approvals are given the day before the work is to commence, and where the results are due the day after the field work is done, standardization is becoming necessary.

When all surveys, whatever their purpose, are performed in a systematic manner, and where the computational and drafting procedures are known beforehand, the reduction of notes into listings or drawings becomes straight forward and easily computerized. On the other hand, if the field system allows for too many variations, the required costs of training instrumentmen and party chiefs increases, as well as the number of possibilities for errors. The old maxim "keep-it-simple" is probably more needed today, now that we have so many tools to complicate things, than ever before.

When we wrote TOPOS, we decided to do just that - "Keep-it-simple". There are really only four field codes to remember; OCCUPY, BACKSIGHT, FORESIGHT, and INTERMEDIATE SIGHT. They are shortened to OCC, BS, FS, and IS. Field procedure always breaks down to the same few routines.

1. Set up on (OCCUPY) a survey point, record the number, the point description and the height of instrument.

2. Backsight on one or more known points, record the number of the point, the description, the height of prism or target; the measured horizontal direction, vertical angle and distance.
3. Foresight to a new point or for checking or doubling to an old point, and record the number, the description, the H.P. and the angles and distance.
4. The intermediate sight is the same as the foresight, but is intended to be used on points of lesser importance and where no checking of or repeat measurements are intended.

Routines 2, 3 and 4 may be repeated as many times as necessary to strengthen the survey or to tie in more points.

Provision is made for prism constants, offsets along line or at right angles and for temporary and permanent scale factors. With the addition of the STORE (a known co-ordinate) command, TOPOS will compute the elevations of all points to which vertical angles were read, print error messages wherever errors are outside the permitted bounds, automatically mean the values of repeated measurements, and calculate the co-ordinates on the mapping plane of all points sighted.

Closed loops may be balanced and adjusted by the simple insertion of the word ADJUST and the closing point number at the beginning of the loop.

Field notes may be plotted by the command PLOT FIELD NOTES.

TOPOS contains many more codes that allow for point creation or manipulation but these are usually considered as computational or drafting functions. As it was designed as a field system, it does not have all the geometric possibilities of COGO although it does permit easy transfer of points between COGO and TOPOS files.

We have deliberately avoided the attempt to have the field party code the data or alter the pickup sequence to create instant final drawings. It is our belief that this would restrict the capability of picking the points for the most efficient survey. We rely instead on simple field sketches and the point labels or descriptions to speak for themselves.

It is quite obvious that we rely on a particular computer program called TOPOS to reduce the field data. This is not mandatory as the structure of the field data is easy to understand and may be handled in any computer or electronic calculator or even by manual methods. It is questionable, however, whether the use of a more simple program makes sense when we consider the high volume of data and the number of error checks that should be made. We will look at the subject of errors later on.

#### Semi-automatic Field Recording

TOPOS is not equipment dependent. Indeed, the majority of points processed by the system so far were surveyed using standard optical theodolites and short range electronic distance meters. The first 12 000 points on the road mentioned in the introduction were done by the stadia method. In these cases, the codes, measurements, and descriptions are written on special field notes, later to be keyed into a computer file and executed.

The process is slower than need be, requiring double handling of the data and is prone to deciphering and keying errors. On the other hand, hard copy made in the field in the more-or-less traditional manner does give a certain feeling of security.

In order to reduce the handling of the data, we decided in the fall of 1979 to move to recording field notes in computer readable form. We considered optical character readers, audio cassette units and various data collectors marketed by survey equipment suppliers. None of the units satisfied our particular notion of what such a device should include. Among others, we determined that the device should have the ability to:

- store as much as two days field work
- be hand held without cases or wires
- allow header information
- prompt for all necessary survey data
- accept alphanumeric descriptions
- store messages
- allow searching and editing
- be flexible
- provide some error checking
- be readable in direct sunlight
- work at extremes of temperatures
- be downloaded in the field
- able to be interfaced to other equipment.

We found the instrument we wanted in the Norand 101XL data collector and had it programmed to our specifications. It is known as the electronic field book or EFB and is being marketed internationally.

#### Automatic Field Recording

When we purchased our first total station theodolite, a Wild TC1, TOPOS had been in use for more than a year. The fact that the methodology was familiar and proven allowed us to have the instrument in production within three days. We recently had the occasion to evaluate the Zeiss Elta 3. We put this device into production the same day we picked it up. We believe that it is the simplicity of our system which permits such short training periods.

Because the electronic theodolites allow for numeric codes only, we have prepared various translators for different applications. The pipe line dictionary is available from me if you would like to have a copy.

#### Errors and their Elimination

If I have made it sound as though we have found the panacea for all survey problems, let me put your mind at ease. We have not!

However, the normal errors in measuring which were caused by such things as poor centering or plumbing, ignoring temperature changes and all the other little things which caused systematic or accumulative errors have largely disappeared. With the current generation of equipment, it is my experience that the measurements are quite often better than the control. Rather than improving our measurements through the process of proportioning, we are actually degrading our measurements to fit control monuments that have been installed at an earlier time perhaps using an inferior technique.

Blunders are another matter. While we can say with certainty that we have fewer blunders today than previously, they are sometimes harder to correct. When graphical field notes were plotted by a draftsman he could usually see immediately if something did not make sense. When property surveys followed boundaries or parallel offsets from them, field angles could be checked at the time of observation to see if they conformed to the theoretical angle. If they did not it was easy to check whether the picketmen were plumbing over the right point. Using modern methods where random traverses are the norm and where measurements are recorded separately from the sketch, the cause and effectual relationships are not so easily seen.

The most common mistake we have found, in several thousand setups, is the failure to properly identify the point occupied or backsighted. Because the computer depends on the point number as the address of the co-ordinates, a wrong point number will automatically give wrong results. We have come to the conclusion that the only way to guarantee the fieldman's success in ascertaining the point number is to actually tag the point with its assigned number.

Impossible though it is to eliminate blunders altogether, they usually can be found. By insisting that every time the instrument is set up two readings be taken for direction and at least one for distance on two different known stations, it is virtually impossible to be on the wrong station or to backsight to the wrong point and not find out about it during computations. It should also be mandatory to observe onto a known station as the last activity before moving the instrument.

Finding the error may be easy, correcting it without a trip to the field is very difficult without some sophisticated software. TOPOS does contain some analysis commands and if sufficient redundancies exist in the data usually the mistake can be corrected in the office. Unfortunately, the time it takes to isolate and correct a blunder this way surpasses by far the amount of time it took to make the measurement in the first place.

Some measuring and recording mistakes do occur. In the case of the electronic theodolite it is usually the failure to remember to do something. These types of errors are usually caught by the operator himself at the time they are made and a little note solves the problem. Others are found at the time of dumping the memory where once again they are easily handled.

Some people are prone to errors; some people seldom make them. When we designed the program for the EFB we recognized this and had a redundancy check put in as an option. When a particular micro-switch is on, the EFB prompts for distance and waits. After receiving input it prompts for the distance again. Failure to key the same number twice prevents the operator from moving on to the next prompt. The horizontal and vertical angle prompts work the same way.

#### Communications and Computations

Once the field work is collected the next operation is to get it into the computer. At the present time we are using either our own VAX 11/780 or a similar computer at a service bureau in Toronto. Communication from anywhere on the continent is through the packet-switching networks of the telephone systems. The EFB may be dumped from any telephone without the need to sign on first at a baud

rate of 1 200. Entering of other field notes or dumps from other devices requires that the computer be accessed by a sign-on procedure. This may be done through a portable terminal and an acoustical coupler at 300 or 1 200 baud.

The larger jobs are most efficiently handled by 1 200 baud modem connected CRTS. In this latter case we connect a printer in serial configuration to the CRT. The normal operation is described as follows:

- call up the computer and sign on
- dump the field notes to a computer file
- translate the data file to a more readable file
- edit the translated file for obvious omissions, and for changes indicated on any hand written notes
- execute the edited file through TOPOS in error detection mode to a output file
- print the output file and debug the errors
- edit the translated file again
- rerun the translated file to get final co-ordinates
- request whatever plots or listings are necessary.

Final drawings are made in head office.

Besides having the extra computational capacity, a large mainframe has other advantages. One of the most important is the ability to communicate in local time to the computer which never sleeps. We use the mail utility to send time sheets to head office and to send and receive messages.

*The ideal computer configuration in our opinion would be to network a micro for local processing to the large host for mass storage and high speed plotting.*

#### Interactive Graphics

No paper today would be complete without some mention of this important topic. TOPOS now provides output through the standard interchange format to whatever system a client may have. It is our commitment to continue with this approach.

#### Applications

TOPOS has been used for many applications. Most have been somewhat topographic in nature but the system will handle other types of surveys as well.

The EFB was designed to allow input for control surveys but the computations would have to be performed outside of TOPOS by such a program as our horizontal adjustment package call HCA.

The small handout illustrates the use of TOPOS on a legal survey of a cottage property. This was an actual project but I have included a bit of extra coding to illustrate some of the other TOPOS commands. The EFB was used as the recording and transfer device.

TOPOS has been widely used for topographic surveying in Saudi Arabia and for as-built surveys of pipelines under construction in Canada. Smaller, but no less interesting applications were the surveying of public utilities in two of Canada's major cities and in measuring quantities of aggregate and marble at various quarry sites.

In addition to the programs mentioned, there are other software systems and programs that use the TOPOS data base. One such program is used to sort all randomly located data into a sequential chainage file and another will find volumes in a borrow pit or stockpile.

I will address these particular applications as we look at the following slides.



ENCROACHMENT SURVEYS FOR LANDS  
ON THE  
INTRACOASTAL WATERWAYS

CLEVELAND POWELL  
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BIOGRAPHICAL SKETCH

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ABSTRACT

The Intracoastal Waterway was constructed in Florida in the thirties by the U.S. Army Corps of Engineers. It is parallel to the Eastern coast line of the State of Florida from Jacksonville to Miami. It is composed of a combination of natural rivers and lagoons which are formed by the coastal barrier reef and man-made "cuts" which connect them. Channels have been designed and developed through these lagoons and in the rivers to maintain a project depth of 12 feet below mean sea level.

The waterway exceeds 300 miles in length and has a deeded perpetual R/W for the channel which averages 500 feet in width. In addition, there are perpetual easements in many different sizes and shapes which are located adjacent to the channel right-of-way which are used for the deposit of material removed from the channel where shoaling occurs. This is where the problem starts, these areas which are used for the deposit of material are called "spoil areas" and they are often prime areas to build a waterfront home or, an island home, in the larger bodies of water. These areas were originally surveyed in the early thirties and most monumentation has been destroyed, all monuments were tied to the land office system, no ties were made to the coordinate system.

To provide legal proof that an improvement has been built on a parcel of land encumbered by a Government easement, a survey is required. The methods of arriving at the areas which require surveys, as well as the technical aspects, prove to be an interesting project.

INTRODUCTION

The Intracoastal Waterway has been in operation between Jacksonville and Miami for 50 years. It has been the subject of a continued attraction to the home owner who desires a waterfront home, marinas, boat yards, seafood restaurants and condominiums. Due to the antiquity of the recording of easements deeded to the Government for the deposit of material and a lack of physical identification such as signs, monuments, etc., many buildings have been placed on this property often without knowledge by the owner that there is any restriction on the property. An updated survey is the first step to notify the owner that there is a problem and to offer conclusive proof that there is a "conflict of interest".

## IDENTIFICATION OF INTERESTS

Three hundred plus miles of waterway is a rather large area to monitor the physical condition of spoil disposal areas and channel right-of-way. Although this is not a surveying problem in the pure form, the boundaries must be identified in relation to the improvements constructed along the waterway to determine if the improvements are located on Government easements. To inspect the lands successfully, an accurate set of maps are required with the latest possible topography laid out at a scale which is large enough to identify features of the topography and small enough to handle from an auto, boat or aircraft.

The basis for the maps must be laid out with reference to the Government land office location of section lines and ties, deed descriptions, as well as up-to-date delineation of topography. The answer to this is the U.S. Army map service quadrangle sheet which shows fairly accurately the location of land lines and utilized controlled aerial photography to establish the topography. Once the maps are prepared at an optimum scale of 1" = 1000' the waterway can be flown at low altitude in a helicopter and the boundaries of the spoil areas can be fairly accurately located as they relate to the sinuositities of the shoreline, creeks, marshes, roads, bridges, section lines which have been cut out, and improvements which are shown on the maps.

## WHICH ENCROACHMENTS REQUIRE A SURVEY

If a spoil area is needed for the placement of material which has historically built up or shoaled in the adjoining channel and, if it is environmentally suitable to receive disposal material, then it should be surveyed.

That sounds like a simple answer to a simple question but it requires a great deal of research as to what the shoaling history is in the area where encroachments have been located and an environment assessment of the area as well as its sizes -- is it large enough to be useful? This requires the service of a handful of experts in individual fields.

## WHAT SHOULD THE SURVEY SHOW

Well here it is, the nuts and bolts of this little article. - Answer - Well it must for beginners, show the location of the limits of the spoil area to the improvements which create an encroachment. This means that the specifications of the survey should include the following items.

1. A retracement of the legal description and recovery of the original monumentation, if any exist.
2. Monumentation of all corners for which the original monuments could not be recovered or were disturbed.
3. Placement of witness signs which readily point out the location of the monuments.
4. Establishment of coordinate values for the monumnets which are found or established which can be used for future recovery of monuments and an expansion of the control net along the waterway.
5. Physical location of all permanent improvements on the spoil area.

6. Preparation of a plat of the disposal area which can be recorded in the county records and used for evidence in court, if necessary.

7. Relation of all established land corners which are used as a reference to locate these spoil areas.

8. Accuracy should be of third order.

9. Designation of monument's names should be based on an established procedure for future identification without repetition.

10 Location of utility easements and overhead power lines.

#### SELECTION OF THE SURVEYING COMPANY

It is the opinion of the Author that all surveys should be performed by contract with a responsible local firm who has knowledge of the location of the local land corners and is recognized by the local public officials and Abstract Companies as an authority on the location of section corners and land divisions. An alternative is the use of a delivery order with an on-going contractor. This will usually increase the cost of the survey due to the requirement for travel time, living expenses and research of the land records and field reconnaissance to locate the land corners. Either method is acceptable but there is a difference in the final cost and it is believed that the owners of the encroachments will more readily accept the findings of a local firm than that of one from another area of the state.

## MODERNIZATION OF PUBLIC LAND SURVEY SYSTEM

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### ABSTRACT

This invited paper reports the progress to date of the Bureau of Land Management (BLM) Cadastral Survey in its efforts to apply new technology to modernize the Public Land Survey System (PLSS). The BLM plans include the integration of cadastral surveys with digital mapping, the improvement of legal Federal recordkeeping, the maintenance of PLSS corner monuments, and the computation and integration of geographic coordinates for both the onshore and offshore PLSS corners. These coordinates will provide a parcel identifier for a proposed Multiple Use Land Data Bank (MULDAB) geographic information system for the public lands. The paper will address only the modernization of surveying and mapping to be consistent with the objectives of this conference. These plans are currently under study by the National Research Council's Committee on Geodesy in the Panel on a Multipurpose Cadastre and the Committee on Integrated Land Data Mapping. Reports of these studies will be published by the National Academy of Science in 1982.

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NORTH CENTRAL DIVISION (Continued)

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NORTH PACIFIC DIVISION

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PACIFIC OCEAN DIVISION

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Fort Shafter  
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SOUTH ATLANTIC DIVISION

Roger A. Brown  
USCE - SADEN-F  
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30 Pryor St.  
Atlanta, GA 30303  
404-221-4696 FTS 242-4696

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30 Pryor St.  
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CORPS OF ENGINEERS SURVEY CONTACTS

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			FTS	Commercial		
<u>Lower Mississippi Valley Division</u>						
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Memphis	H/T	W. J. Selvo	222-3238	901/521-3238	668 Clifford Davis Federal Bldg.	38103
		Sam Lehr	222-3239	901/521-3239	668 Clifford Davis Federal Bldg.	38103
		Tom Verna	222-3465	901/521-3465	668 Clifford Davis Federal Bldg.	38103
Vicksburg	H/T	E. L. Howe	542-5712	601/634-5712	PO Box 60	39180
		E. L. Boren	542-5266	601/634-5266	PO Box 60	39180
		L. C. Fumbanks	542-5266	601/634-5266	PO Box 60	39180
New Orleans	H/T	Wayne Weiser	687-5152	504/733-5152	PO Box 60267	70160
		Don Eames	687-5152	504/733-5152	PO Box 60267	70160
		Leonard Halpen	687-5152	504/733-5152	PO Box 60267	70160
<u>Missouri River Division</u>						
Omaha	H/T	M. W. Taylor	864-4614	402/221-4614	6014 USPO & Courthouse	68102
Kansas City	H	W. L. Allcock	758-5671	816/374-5671	601 E. 12th St.	64106
	T	D. M. Vanhaverbeke	758-5354	816/374-5354	601 E. 12th St.	64106
<u>North Atlantic Division</u>						
Philadelphia	H/T	H. R. Spies	597-4745	215/597-4745	US Custom House, 2nd & Chestnut St.	19106
Norfolk	H/T	Roger Pruhs	827-3130	804/441-3130	803 Front St.	23510
New York	H/T	Raymond Elmore	264-0181	212/264-0181	26 Federal Plaza	10007
		Buck Waroner	264-0181	518/273-0870	Albany Field Office	10007
New England	H/T	Jim O'Leary	839-7526	627/894-7526	424 Trapelo Rd.	02154
Baltimore	H	Dick Buck	922-3663	301/962-3663	PO Box 1715	21203
	T	Everett Moore	922-2309	301/962-2309	PO Box 1715	21203

NOTE: H-hydrographic.  
T-topographic.

CORPS OF ENGINEERS SURVEY CONTACTS

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			FTS	Commercial		
<u>North Central Division</u>						
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Detroit	H/T	C. E. Lamphere	226-6816	313/226-6816	P0 Box 1027	48231
Rock Island	H/T	W. C. Riebe	386-6268	309/788-6361	Clock Tower Building	61201
Chicago	H/T	Tech Engineering Br. Gen Engr Sec.	353-6502	312/353-6502	219 S. Dearborn St.	60604
St. Paul	H/T	G. Kletzke	725-7544	612/725-7544	1135 USPO & Custom House	55101
<u>North Pacific Division</u>						
Alaska	H/T	B. J. Adams	552-4341	907/552-4341	Box 7002, Anchorage	99510
Portland	H	J. Jurisons	423-6301	503/221-6301	P0 Box 2946	97208
	T	L. Alford	423-6474	503/221-6474	P0 Box 2946	97208
Seattle	H	R. E. Parker	399-3400	206/764-3400	P0 Box C-3755	98124
	H	R. Johnson	399-3413	206/764-3413	P0 Box C-3755	98124
	T	L. Signani	399-3535	206/764-3535	P0 Box C-3755	98124
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<u>Ohio River Division</u>						
Pittsburgh	H/T	T. E. Taylor	722-6826	412/644-6826	1000 Liberty Ave., Federal Bldg.	15222
Huntington	H/T	R. R. Applegate	924-5698	304/529-5698	P0 Box 2127	25721
Louisville	H	Don Purvis	352-5720	502/582-5720	P0 Box 59	40201
	T	Boyd McClellan	352-5661	502/582-5661	P0 Box 59	40201
Nashville	H	H. Davis	852-5607	615/251-5607	P0 Box 1070	37202
	T	R. Buttery	852-5954	615/251-5954	P0 Box 1070	37202
<u>South Atlantic Division</u>						
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Mobile	H/T	J. W. Reaves	537-3761	205/694-3761	P0 Box 2288	36628

CORPS OF ENGINEERS SURVEY CONTACTS

District	Hydrographic/ Topographic	Contact	Telephone		Address	Zip Code
			FTS	Commercial		
South Atlantic Division (Continued)						
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Charleston	H/T	I. B. Kyzer	677-4365	803/724-4365	PO Box 919	29402
Jacksonville	H/T	Bill Bergen	946-1607	904/791-1607	PO Box 4970	32232
South Pacific Division						
Los Angeles	H/T	E. M. Bratcher	798-5550	213/688-5550	PO Box 2711	90053
Sacramento	H T	J. S. Poland J. G. Stapleton	448-7550 448-3364	916/371-7550 916/440-3364	PO Box 935, West Sacramento 650 Capital Mall	95691 95814
San Francisco	H T	Ron Ard Bill Angeloni	556-2404 556-6965	415/556-2404 415/556-6965	211 Main St. 211 Main St.	94105 94105
Pacific Ocean Division						
Pac Ocean Div.	H/T	V. B. Kalino	--	--	Bldg. 230, Fort Shafter, Honolulu	96858
Southwestern Division						
Tulsa	H T	Harry Hartwell R. E. Ramsey	736-7206 736-7845	918/581-7206 918/581-7845	PO Box 61 PO Box 61	74121 74121
Kerr Reservoir	H	C. E. Weddle	736-2216	918/775-4475	Star Rt. 4, Box 182, Sallisaw, Okla.	74955
Little Rock	T	J. T. Long	740-5661	501/378-5661	PO Box 867	72203
Little Rock Pine Bluff Area Office	H H	Ted Cook DeWayne Combs	740-5679	501/378-5679 501/534-0451	PO Box 867 PO Box 7835, Pine Bluff, Ark.	72203 71611
Dardanelle Area Office	H	T. Spencer	740-5137	501/968-5088	PO Box 1087, Russellville, Ark.	72801
Galveston	H/T	David Campbell	527-6085	713/766-3085	PO Box 1229	77553
Ft. Worth	T	Dennis Anderson	334-2281	817/334-2281	PO Box 17300	76102
Albuquerque	H/T	Don Luna George Baca	474-2715 474-2715	505/766-2715 505/766-2715	PO Box 1580 PO Box 1580	87103 87103

CORPS OF ENGINEERS SURVEY CONTACTS

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			FTS	Commercial		
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	H	G. C. Downing	542-2747	601/634-2747	PO Box 631, Vicksburg, MS	39180
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Coastal Engr. Research Center	H	Wm. Birkemeier		919/261-3511	FRF, S.R. Box 271, Kitty Hawk, N.C.	27949
Office, Chief of Engineers	H/T	Ed East	272-0216	202/272-0216	DAEN-CWE-BU, Wash, D.C.	20314
	H/T	M. K. Miles	272-0216	202/272-0216	DAEN-CWE-BU, Wash, D.C.	20314
	H/T	R. F. Malm	272-0232	202/272-0232	DAEN-CWE-BA, Wash, D.C.	20314

# SURVEY EQUIPMENT SUPPLIERS

<u>Company</u>	<u>Person to Contact/ Telephone No.</u>	<u>Product/Service</u>
Abema, Inc. 10 Fitch Street, PO Box 775 Norwalk, CT 06856	Mr. Louis Nigro (203) 838-2822 800-243-5005	Topographic Survey Supplies
Allied Surveyor Supplies Mfg. 3225 E. 47th St. PO Box 27367 Tucson, AZ 85726	Esther Feldman (602) 622-6011	Survey Monuments
Alpha Electronics 8185 S. Grant Way, PO Box 2073 Littleton, CO 80122	Ron Elkin (303) 795-8435 (205) 758-5810	Distance Measuring Equipment
American Congress on Surveying and Mapping 210 Little Falls St. Falls Church, VA 22046	John C. Vehlinger	Professional Society
AMETEK/Straza Division 770 Greenfield Dr. PO Box 666 El Cajon, CA 92022	Bob Beme (714) 442-3451	Doppler Navigators
Autometric 5205 Leesburg Pike Suite 1308, Skyline 1 Falls Church, VA 22041	J. C. Howland (202) 998-7606	Topographic Survey Suppliers
Bartex, Inc. PO Box 3348 Annapolis, MD 21403	Harry Barnes (301) 261-2987	Tide Gage and Telemetry
Bernsten Cast Products 100 E. Broadway Madison, WI 53704	Bill Garrott Bill Rushing (608) 221-1300	Survey Monuments
Craven-Thompson & Assoc, Inc. 5901 N. W. 31st Avenue Ft. Lauderdale, FL 33309	Leonard Wood Robert A. Best (305) 971-7770	Contract Surveys
Cubic Western Data 5650 Kearny Mesa Dr. PO Box 80787 San Diego, CA 91258	Dick Derenthal Chuck Hempel Bill Newsome (714) 268-3100 FTS 895-5000	Distance Measuring Equipment
Data-Sonics PO Box A61 North Falmouth, MA 02556	Dave Porta (617) 563-7311	Suspended Particulate Detectors
Del Norte Technology PO Box 696 Euless, TX 76039	James C. Stegall (817) 267-3541 Roy Fort (713) 464-8764	Distance Measuring Equipment



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<u>Company</u>	<u>Person to Contact/ Telephone No.</u>	<u>Product/Service</u>
Digital Design & Development Industrial Park PO Box 225 Hingham, MA 02043	Stan Zamkow (617) 668-1090	Custom Microcomputer Systems
E. Phil Harris Co. 5352 First Avenue, N. Birmingham, AL 35212	Tommy Dudley (205) 595-3796 1-800-633-6457	Topographic Survey Equipment Sales, Rentals, Repairs
Edo Western 2645 S. Second St. Salt Lake City, UT 84115	(801) 486-7481	Sub-bottom Profilers Doppler Navigations
EG&G 151 Bear Hill Rd. Waltham, MA 02159	Ross Johnson (617) 890-3710 (408) 734-4616	Sub-bottom Profilers Side Scan Sonar
ENDECO Tower Bldg Marion, MA 02938	Bob Skinder (617) 748-0366	Environmental Measuring Equipment
Engineering Services Assoc 1500 Massachusetts Washington, DC 20005	Michael Wasteneys Roger Justice (202) 659-8800	Contract Surveys & Survey Equipment
Florida Level & Transit Co., Inc. 3543 West Beaver St. Jacksonville, FL 32205	Jim Wehrenberg 388-3093	Contract Surveys
Fluid Dynamics Corp. 12 Watson Lane Setauket LI, NY 11733	Joseph McCambridge (516) 751-3035	Beach Erosion Abatement Equipment
George F. Young, Inc. PO Box 683 St. Petersburg, FL 33731	Millard L. Cutler (813) 822-4317	Contract Surveys
Hewlett Packard PO Box 301 Loveland, CO 80537	Area Sales Rep in all parts of US	Optical DME Total Surveying Station Data Acquisition Systems Data Processing Systems
Hydrographic Society NOAA/NOS Code OA/C35X3 6001 Executive Blvd. Rockville, MD 20852	Jack L. Wallace (301) 443-8231	Professional Society
Innerspace Technology, Inc. One Bohnert Place Waldwick, NJ 07963	Steve Holowacz Clyde Buchanan (201) 447-0398	Depth Digitizers Depth Recorders
Harvey-Lynch, Inc. 10669 Richmond Houston, TX 77042	Steve Duncombe (713) 780-2177	Magnetometers

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International Technology, Ltd. (Itech) 9000 Clay Rd. Suite 110, Pineway Business Ct. Houston, TX 77040	Warren Morris (713) 939-7419 -7519	Contract Inertial Surveys
Kern Instruments, Inc. Geneva Rd. Brewster, NY 10509	Mr. O. Schwarzer (914) 279-5095	Topographic Survey Equipment Field Instruments
Keuffel & Esser Co. 20 Whippany Rd. Morristown, NJ 07960	Chuck McClinch David Norris (201) 285-5303 (804) 625-2591	Topographic Survey Equipment Field Survey Systems Office Computer Survey Systems
Klein Associates, Inc. Klein Dr. Salem, NH 03079	W. H. Key (603) 893-6131 FTS 834-7011	Side Scan Sonar
Krupp Atlas Elektronik 241 Erie St. Jersey City, NH 07302	Doug Blue (713) 645-4005 (713) 783-8220	Depth Sounders DME Computerized Survey Systems Sweep Systems
The Lietz Company 9111 Barton St., Box 2934 Overland Park, KS 66201	V. Winchell (913) 492-4990	Topographic Survey Equipment
Marshall, Macklin, Monaghan Ontario Ltd. 275 Duncan Mill Road Don Mills, Ontario M3B2Y1	Dave Johnston (416) 449-2500	Contract Surveys
Monarch Boat Co. PO Box 210 Monticello, OK 71635	J. H. Smith (501) 367-5361	Survey Boars
Motorola, Inc. Government Electronics Div Mail Drop T South Price Road Tempe, AZ 85282	Randy Krajcher Terry Hern Norm Iverson Bill O'Donnell (602) 831-4265	DME Complete Survey Systems
Murphy, Parish, Kilgore, Inc. Suite 101 1000 S. Woodward Ave. Birmingham, MI 48011	T. N. Parish (313) 646-8770	Contract Surveys
NAVTRONIC AS Markvanger 9 DK8260 Viby J Denmark	Erik Brinch Nielsen Paul Kjaer	Depth Sounders Sweep Systems Computerized Survey Systems

# SURVEY EQUIPMENT SUPPLIERS

<u>Company</u>	<u>Person to Contact/ Telephone No.</u>	<u>Product/Service</u>
Nicolet Zeta 101 Governor's Dr. Suite 504, Bank of Huntsville Bldg. Huntsville, AL 35810	Bill Farmer 205/533-2645 Dick Cherington (301) 459-2940	Plotters
Ocean Research Equipment PO Box 709 Falmouth, MA 02541	Ron Penton (617) 548-5800	Sub-bottom Profilers Side Scan Sonar
Odom Offshore Surveys PO Box 927 Baton Rouge, LA 70821	L. E. Whittington Harold Odom (504) 769-3051	Contract Surveys Survey Systems Depth Sounders DME Range Azimuth Systems
Post, Buckley, Schuh & Jernigan 6850 SW 40th St. (Bird Rd) Miami, FL 33155	Ken Aller (305) 661-7275 David J. Rauch (404) 261-7275	Contract Surveys
RACAL - Decca Survey, Inc. 10401 West Office Dr. Houston, TX	J. D. (Jim) Cain Tom Sellers (713) 783-8220	Contract Surveys Complete Survey Systems
Raytheon Ocean Systems Co. 10 Risho Ave Westminister Park E. Providence, RI 02914	Ray Cote Tom Glennon John Lorea (401) 438-1780	Depth Measuring Equipment Contract Surveys
Riley Park Hayden & Assoc., Inc. 136 Marietta St. NW Atlanta, GA 30303	Ralph L. Hayden (404) 577-5600	Contract Surveys
Ross Laboratories 3138 Fairview Ave, E. Seattle, WA 98102	Wayne Ross Hy Pollack (202) 324-3950	Depth Measuring Equipment Sweep Systems
Schonstedt Instrument Co. 1775 Wiehle Ave. Reston, VA 22091	T. J. Enix Jim Inkster (703) 471-1050	Magnetometers
Science Applications, Inc. 202 Thames St. Newport, RI 02840	Jerry Cook Robert Morton (401) 847-4210	Contract Surveys
Sea Systems Corp. PO Box 1042 Deerfield Beach, FL 33441	Dallis Copeland Sue Townsend (305) 421-4622 (305) 421-4688	Surveying Equipment
Southern Resource Mapping Corp. 1360 Ocean Shore Blvd., Suite 14, PO Box 365 Ormond Beach, FL 32074	Wm. D. Butler Neil Notestine (904) 677-2963 (904) 677 2968	Contract Surveys

# SURVEY EQUIPMENT SUPPLIERS

<u>Company</u>	<u>Person to Contact/ Telephone No.</u>	<u>Product/Service</u>
Spann International 7330 Shoeman Lane Scottsdale, AZ 85251	Roger Campbell (602) 994-3663 (703) 620-6072	Contract Inertial Surveys
T. Baker Smith & Son, Inc. 4608 Jasper St. Metairie, LA 70002	Charles Tobelman (504) 454-8355	Contract Surveys
Teledyne/Radist PO Box 1275 Hampton, VA 23361	Dexter Phibbs Floyd Gibbs (804) 723-6531 FTS 827-3000	Distance Measuring Equipment
Teludist PO Box Y Mastic, NY 11951	Roger Justice (516) 399-5843	Distance Measuring Equipment
The Carl Zeiss Co. PO Box 378 Donald, OR 97020	(503) 678-1271	Topographic Survey Equipment Field Instruments Survey Data Processing Equipment
Topcon Instruments 1090 McConnell Dr. Decatur, GA 30033	Josh Veal (404) 634-9821	Land Surveying Equipment
Wild Heerbrugg Instr., Inc. 465 Smith Street Farmingdale, NY 11735	Charles E. McNoldy (516) 293-7400 (703) 791-5800 (703) 534-4779	Topographic Survey Equipment
Wimpol, Inc. PO Box 219218 Houston, TX 77218	Colin Weeks (713) 492-2054	Survey Systems

## HYDROGRAPHIC SURVEY EQUIPMENT

Manufacturer	Single Freq. Depth Recorders	Switchable Freq. Depth Recorders	Dual Freq. Depth Recorders	Depth Digitizers	Heat Correction Sensor	Sweep Systems	Sub-Bottom Profilers	Side Scan Sonar	Range-Azimuth Positioning System	Range-Range Positioning System	Three-Range Positioning System	Four-Range Positioning System	Doppler Navigators	Computer Controlled Survey Systems	Application Software	Tide Gage & Telemetry	Survey Boats
Alpha									X								
AMETEK													X				
BARTEX																X	
Cubic										X	X						
Data Sonics			X														
Del Norte									X	X	X	X					
Digital Des & Dev														X			
EG&G							X	X									
Edo Western							X	X									
Innerspace	X		X	X													
Kilbane																X	
Klein								X									
Krupp	X	X			X	X								X	X		
Monarch																	X
Motorola										X	X	X		X	X		
Navitronic	X	X	X	X	X	X								X			
Odom	X								X	X				X	X		
ORE	X				X		X	X									
RACAL										X	X	X		X	X		
Raytheon	X	X		X		X	X										
Ross	X		X	X		X											
Raydist										X							
Tellurometer										X	X						

LAND SURVEY EQUIPMENT

Manufacturer	Optical DME	Microwave DME	Tachometers	Theodolites	Transits	Gyro	Levels	Survey Accessories	Seismographs	Magnetometers	Inertial Surveyor	Survey Monuments	Satellite Paint Positioning	Data Acq. System	Data Processing Systems
Alpha	X														
Abema												X			
AGA	X														
Allied Survey												X			
Bernsten												X			
EG&G									X	X				X	X
Hewlett-Packard	X			X										X	X
JMR													X		
Kern	X		X	X			X								
K&E	X			X										X	X
Krupp-Atlas	X														
Lietz	X			X	X	X	X	X							
Magnavox													X		
Motorola													X		
Raytheon										X					
Tellurometer		X													
Wild	X		X			X	X								
Zeiss	X	X	X	X			X	X						X	X
Cubic		X													

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